FISCAL YEAR 1986 DEPARTMENT OF ENERGY AUTHORIZATION

(Transportation Programs)

HEARING

BEFORE THE

SUBCOMMITTEE ON TRANSPORTATION, AVIATION AND MATERIALS

OF THE

COMMITTEE ON SCIENCE AND TECHNOLOGY U.S. HOUSE OF REPRESENTATIVES

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*Ranking Republican Member.
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FISCAL YEAR 1986 DEPARTMENT OF ENERGY AUTHORIZATION

(Transportation Programs)

WEDNESDAY, FEBRUARY 27, 1985

HOUSE OF REPRESENTATIVES, COMMITTEE ON SCIENCE AND TECHNOLOGY, SUBCOMMITTEE ON TRANSPORTATION, AVIATION AND MATERIALS,

Washington, DC.

The subcommittee met, pursuant to notice, at 2:05 p.m., in room 2325, Rayburn House Office Building, Hon. Dan Glickman (chairman of the subcommittee) presiding.

Present: Representatives Glickman, Lewis, Packard, and Boehlert.

Mr. GLICKMAN. Why don't we get started here.

Today the subcommittee will consider the administration's budget request for transportation-related research by the Department of Energy.

The importance of this kind of work is indicated by the fact that over 60 percent of all petroleum consumed in this country is used in the transportation sector. And over three-quarters of that is used by motor vehicles. So, clearly this is an attractive target for research if we hope to reduce our dependence on foreign oil.

Unfortunately, support within the administration for research on alternative automotive engines and fuel has weakened considerably with the current world oil glut.

But the underlying rationale for attention to this area hasn't changed. Our economic well-being, as well as our national security, is still highly dependent on the whims of a few countries in a turbulent part of the world. The wisdom shown by those who drafted both the Electric Vehicle Act and and Automotive Propulsion Act is as valid today as it was then. We must still provide for the very real possibility that alternative propulsion systems and alternative fuels will be needed. To do otherwise would be to abdicate an important Federal responsibility; namely, to provide for the continued security of its citizens in the broadest sense.

Obviously we have a budget crisis that we absolutely must deal with this year. And that means holding programs at or, in some cases, below last year's levels. But, as I look at this request, I see a 30-percent cut from the 1985 amount. And that makes very little sense, particularly when you consider that the Pentagon is requesting huge increases, partly to enhance its ability to protect Middle

East oil supplies. Why not spend just a miniscule portion of that to develop alternatives to that oil?

For example, the administration has once again called for termination of the Stirling Engine project less than 2 years before final demonstration of the original legislative goals and despite the clear intention by Congress to complete it. Important work on alcohol fuels and electric vehicle battery development has also been curtailed.

On the positive side, I'm pleased to note that the fiscal year 1986 program includes funding to complete the gas turbine engine project and for expanded research on high temperature materials, a key to more energy efficient engines in the future.

So, I look forward to the Department's testimony and to discussing the basis for its budget request.

Now, I would like to call on my ranking Republican, my ranking minority member, Mr. Lewis of Florida, for any comments he may wish to make.

Mr. LEWIS. Thank you, Mr. Chairman.

I look forward to the testimony of the distinguished witnesses who are here today representing the private sector and the Department of Energy in transportation research and development.

The budget submitted by the Department of Energy this year continues to reflect the administration's philosophy that basic generic research should take precedence over systems development. This budget is surely a disappointment to many, but in face of the massive budget deficits forecast for this year, I don't know what else could be done.

I support the increased emphasis on structural ceramics research, which I believe is the key to the success of the advanced heat engines. I was particularly pleased to see that the Garrett/Ford and Allison/Pontiac teams are increasing their cost-sharing to permit both to complete the proof-of-concept automotive gas turbine program. This technology appears to have the potential to provide an attractive fuel efficient alternative to the conventional spark ignition engine, and this display of confidence by the automotive industry is reassuring.

Mr. Chairman, we all support the goals of these programs, but perhaps we should question how cost effective they have been compared to the private sector's own initiatives to reduce fuel consumption. Moreover, with the automotive industry now enjoying record profits while the Federal Government is trying to cope with a $200 billion deficit, I believe we must question the appropriateness of continuing some of these programs.

Sorting out the various programs here to determine how best to accomplish our goals with the limited resources will be a real challenge—and I look forward to hearing the witnesses here today share their views with us on how this might be done.

Thank you, Mr. Chairman.

Mr. GLICKMAN. Thank you, Mr. Lewis.

Mr. Packard, do you have any comments.

Mr. PACKARD. Not at this time, thank you.

Mr. GLICKMAN. Mr. Pat Collins, it is a pleasure to see you here again this year, and we welcome you. I notice you have a group of people with you. Why don't you just proceed and introduce them.

I would tell you that I'm kind of going to start something new. We have a little bell here and we find, when people know they're under the gun, they tend to complete their testimony quicker so we can have more time for questions. Rest assured that your entire testimony, and the testimonies of all the witnesses, will appear in the record. I would tell you, that if you summarize your testimony, your summary also appears in the record as well. In any event, we will try to set this for about 10 minutes per witness. To the extent that you can stay within that, I would appreciate it.

STATEMENT OF PAT COLLINS, UNDER SECRETARY, U.S. DEPARTMENT OF ENERGY, WASHINGTON, DC; ACCOMPANIED BY DONNA FITZPATRICK, PRINCIPAL DEPUTY ASSISTANT SECRETARY FOR CONSERVATION AND RENEWABLE ENERGY; AL STREB, DEPUTY ASSISTANT SECRETARY FOR CONSERVATION; AND MEL CHIOGIOJI, DIRECTOR, OFFICE OF VEHICLE AND ENGINE R&D

Mr. COLLINS. Thank you very much, Mr. Chairman. It is a pleasure to be back again, and I think you will find that in many of the areas that we had received advice from the committee last year, we have been able to be in compliance with that advice. I think it has improved the product and the cost-effectiveness for the Federal Government in general.

Today I am accompanied by Donna Fitzpatrick, the Principal Deputy Assistant Secretary for Conservation and Renewable Energy; Mr. Al Streb, the Deputy Assistant Secretary for Conservation; and Dr. Mel Chiogioji, our Director of the Office of Transportation Systems.

I appreciate this opportunity to appear before you and I have a statement that I would like to have included in the record, and let me summarize.

I think that the 1986 budget for the Energy Conservation R&D Program for Transportation is consistent with, and supports the goals and objectives of the fourth national energy policy plan. The overall goal for national energy policy is to foster an adequate supply of energy at reasonable costs. The strategies for achieving this energy policy goal are to minimize Federal control and involvement in energy markets while maintaining public health and safety and environmental quality; and, second, to promote a balanced and mixed energy resource system.

The primary goal of the Federal Energy Conservation Program for Transportation is to improve the energy efficiency and enhance the flexibility of fuel options in the transportation end-use sector. In allocating our resources, we are concentrating on applying Federal funds only where they are most effective, in supporting research and development efforts where the potential payoff is high but which private industry cannot be expected to pursue because the results are difficult to predict or the return on investment would require such a long time to be realized.

Efforts will continue to focus on improved dissemination of results of our R&D programs, and expanded collaboration with the private sector.

The fiscal year 1986 budget request for Vehicle Propulsion R&D provides $15 million for the completion of the automotive gas turbine full-engine proof-of-concept development project, with both the Allison/Pontiac and Garrett/Ford teams reaching engine dynamometer testing of completely ceramicized high-temperature configurations. Both teams were allowed to continue full-engine development in fiscal year 1985 because of substantial increases in contractor cost sharing. These cost sharing levels will continue in fiscal year 1986. As you know, this was a suggestion of this committee that we appreciate and realize the cooperation of our private sector partners.

In the Automotive Stirling Engine project, the evaluation of the two MOD I engines loaned to industry has been completed. A final design of a MOD II engine will be completed this year. With the transfer of the results of the industry evaluation and all designs and test and performance data to industry for their assessment of the potential of Stirling Engine technology for automotive propulsion systems, the goals of the proof-of-concept strategy will be accomplished, we think. We are, therefore, not requesting additional funds for Stirling engine R&D in fiscal year 1986, and that really makes up for the difference, Mr. Chairman, in our budget. In fact, we have actually enhanced two other areas: structural ceramics and adiabatic diesel work, in addition to that.

A total of $3 million has been requested for continuation of the heavy-duty adiabatic diesel project. Component evaluations of developed ceramic structures in a single cylinder engine test cell will be utilized for second stage component developments. Conceptual designs for a base-line multicylinder proof-of-concept heavy-duty adiabatic diesel engine will be carried out with industry.

Six point one million dollars has been requested for the Electric and Hybrid Vehicle R&D where the major emphasis continues to be development of the battery technology for vehicle propulsion. In fiscal year 1986, complete vehicle lead-acid and nickel-iron batteries systems that are expected to meet performance goals of a range of about 100 miles on a single charge, with a battery life of about 60,000 vehicle miles and acceleration capability better than a diesel vehicle will be delivered and tested.

Efforts will continue in fiscal year 1986 on a dual-shaft propulsion system technology development for commercial van application that incorporates an a.c. induction motor, multispeed automatic transaxle, controller/power inverter technologies and the nickel-iron battery system.

Testing and evaluation of new electric vehicle technologies will continue to be carried out by the Electric Vehicle Test Center at the Idaho National Engineering Laboratory, as well as in operational fleet vehicles.

The fiscal year 1986 request provides $9.3 million for the Advanced Materials Development Program. These funds will be used to continue phased activities on existing research projects and to initiate new work on a scale-up of improved powder synthesis, composite processing, and life prediction for composite materials.

We have also requested $3 million for the final increment to complete the High-Temperature Materials Laboratory building and

begin development of operational procedures and research staff requirements.

We have requested $1.6 million for the Alternative Fuels Utilization Program for fiscal year 1986 to continue performance, emissions, wear, and optimization investigations on conventional and advanced engines using synthetic fuels and performance investigations using methane fuel.

With regard to the methanol-fueled vehicle demonstration, a two-phase program has been developed. Phase 1, initiated this year, will establish limited controlled fleet operations and refueling sites. Operational data collected in phase 1 will be utilized to establish specifications for phase 2, where GSA will procure a large number of production vehicles for integration into the Federal fleet. Since phase 1 is not expected to be completed until late in fiscal year 1986, the funds appropriated for fiscal year 1985 are sufficient to maintain continuity in this program. The phase 1 effort will provide GSA and Federal fleet operators with necessary specifications and operational data so that it will possible to order methanol vehicles through normal acquisition procedures in the Government.

Finally, we are requesting $1.7 million for 28 equivalent full-time positions to provide direction and management for this program. We are confident that the fiscal year 1986 budget proposals will increase our understanding of the potential of virtually all of the most promising energy conservation technologies in the transportation field and will substantially contribute to the base of technical information required for informed decisionmaking.

Mr. Chairman, we are pleased to have the advice we have received from Congress and especially from this subcommittee, and that we could join in the philosophy of Members as expressed last year in so many of the projects. We also appreciate the outstanding cooperation of many private sector individuals, some of whom are represented here today. We think this is the type of partnership that we would like to see in the future.

Thank you, Mr. Chairman.

Mr. GLICKMAN. Let me just talk for a moment about a couple of items within this thing. With regard to the Stirling engine project, I wonder if you might talk about why you decided to basically complete work this year and not to complete the project through MOD II.

Mr. COLLINS. I think that basically we think we have learned a great deal through our cooperation with the private sector people who are involved here and, at this point in time, although we have done some component work in MOD II, we will have accomplished what we think is the general thrust of the subcommittee in this area. It is up, at this point, to the private sector if they would like to continue this, to participate more fully in that.

Mr. GLICKMAN. I understand you've had discussions with Army officials with regard to the Stirling. Can you tell me what they said to you?

Mr. COLLINS. That's correct. I think that they view it very similarly to us—that the Stirling engine has a great potential that is possibly stronger in other fields than the transportation area. For example, a mobile generator 30 kilowatt device may fit into their

program. I think that is an outstanding possibility. It would be an excellent market, and consistent with our findings.

Mr. GLICKMAN. With regard to the Stirling, has the project actually demonstrated the original goal of 30 percent improvement in fuel efficiency?

Mr. COLLINS. No, it is just about at a par with conventional engines.

Mr. GLICKMAN. Is the MOD II projected to in fact do that?

Mr. COLLINS. We think it would.

Mr. GLICKMAN. But you still don't see any reason why you should go ahead and complete that in light of all the dollars that have been spent on it today?

Mr. COLLINS. That's always a tough question. It is the opinion of the professionals in our department that it would achieve that the 30 percent fuel reduction. Quite frankly, our views are well known throughout the private sector and if they would like to pursue that in a variety of areas, even in the Federal Government, that would be more appropriate.

Mr. GLICKMAN. With limited funds of course.

Mr. COLLINS. I'm not saying anything bad about the Stirling engine. This program has been run very well by the contractors.

Mr. GLICKMAN. We'll be hearing from the Stirling people later and I'm sure they will have their specifics about the program.

Let me talk to you for a moment about methane.

Mr. BOEHLERT. Mr. Chairman, if I may interject, what would be the cost of continued development of the MOD II?

Mr. COLLINS. About $28 million and would probably take about 2 years.

Mr. GLICKMAN. How much for 1986 and how much for 1987?

Mr. COLLINS. $17 million and $11 million.

Mr. GLICKMAN. With respect to methane, last year I proposed a program to gather operating data on existing methane fuel fleets and distribute it, so that others interested in the fuel could evaluate its advantages to their own applications. I wonder how you feel about a program like that?

Mr. COLLINS. We are pursuing a data base that would be available for people to make a decision predicated on that. I am having some meetings later this month, or the first of next month, along this line to see if we can do even more. We've had very successful programs in our alternative fuels task force within the Department and without, as a matter of fact, bringing people together to discuss a great many of the alternatives. We've got the best professionals in Government and industry and we are pursuing a variety of possibilities. Quite possibly, we may need to enhance our methane work. Our data base is excellent and will be available.

Mr. GLICKMAN. Your request shows no funds for alcohol fuels work at all. Why?

Mr. COLLINS. In the area of methanol, so far as that goes, we are going to have a fleet that should be providing proof in a variety of different engines in a variety of locales. We've worked extensively with the GSA, as well as DOD and other large utilizers such as the Post Office Department and the Department of Agriculture, and I think that we will have a pretty good feel about the ability to use methanol at the conclusion of the year. I'd say also that there is

some research being done in our fossil fuel division of the Department of Energy that is fairly promising. I discussed this a little bit last year. It is not on a large scale, but it looks like there are some outstanding possibilities.

Mr. GLICKMAN. Do you think you are being lulled, not just you but American industry, into the fact that you can buy gasoline for less than a dollar and nobody is really too concerned about energy problems?

Mr. COLLINS. Both the prior Secretary of Energy and the present Secretary and myself are all concerned about that. Because of the lower prices presently, we are concerned that we may be lulled into complacency on a variety of fronts here. We think we ought to have a strong research program; a practical one. I think that it has been changed quite a bit in the last year and we are pleased about that. It is a tough question and a tough judgement to make. With our alternative fuels task force, we think we have a fairly broad and fairly comprehensive look at the situation and don't hesitate to enhance any of the areas that would be involved.

Mr. GLICKMAN. I must tell you that, while I'm not totally pleased with your budget, I'm surprised you've got any money in here at all coming before us because I thought if Mr. Stockman had his way, he would have let the marketplace take care of everything and we would have ended up with no programs at all. I don't know if you had anything to do with that, but if you did I congratulate you.

Mr. LEWIS. Thank you, Mr. Chairman.

I would like to ask Ms. Fitzpatrick a question. Where do we stand now as opposed to where we stood a couple of years ago with a conservation program and renewable energy and where do you expect we'll go from here?

Ms. FITZPATRICK. I think that our programs have evolved to try to address the basic technical problems that exist both in energy use technologies and energy production technologies from renewable resources. We are trying to work much more closely with industry so that whatever is done in Federal research can move very quickly to the private sector so that it can be utilized in commercial applications. We also work with them in the planning stages so that we'll know what it is that they need in order to meet market needs.

I think we have made definite progress in this and it is important, when you're looking at budget moneys over a time of 5 or 6 years, to understand that while budget numbers have been coming down, the emphasis has shifted from demonstration projects which don't add to technological knowledge to the kind of research that we are trying to do today.

Definitely, the country still has a long way to go to reach optimum energy efficiency and also to utilize all of our available energy resources. We think that our overall conservation and renewable research program is a logical, reasonable, and doable way to achieve those goals.

Mr. LEWIS. In line with the comments the chairman made, do you feel that the private sector is taking the strides necessary for renewable energy sources in a number of areas, and are they really

concerned about the possibility that we were scared to death of in 1972; that we were going to run out of fossil fuels?

Ms. FITZPATRICK. I think that the people who are trying to produce, develop, and market renewable energy technology devices are very aggressive. The problem is to convince people who are the potential customers that in the long run, over the life-cycle of the system, they are better off with renewable technology than with the fossil fuel technology. The problem is two-fold; No. 1, there is a sense of complacency because we don't have gas lines and you can buy gasoline for a dollar or less a gallon and people forget very quickly both the threat that we were faced with very recently, and, the inevitability of the depletion of our fossil resources. The other problem has to do with the initial cost of a renewable energy system. The system costs a lot to set up—more than a coal-fired boiler—but the life cost of a renewable system really is competitive because you're not paying for fuel over the 20- or 30-year life cycle. People need to learn to be more far-seeing about the real cost of their energy over the life cycle of the system. We need to be sure that we don't do things that discourage people from making capital investments so that the renewable technologies can become competitive. I'm talking, for example, about tax policy.

Mr. LEWIS. What is your relationship and your position with the petroleum companies with respect to them conversing with you and holding dialog with you and members of your department as far as their work on renewable energy fields?

Ms. FITZPATRICK. Well there are some petroleum companies who are interested in renewable technology. ARCO stands out, for example, as being very interested in photovoltaics. Some of them do realize that they are going to have to diversify because they are working with a finite resource. We certainly encourage them in that.

Mr. LEWIS. Have any of these companies in discussion with you come across with any percentage of their profits they put back into renewable energy research?

Ms. FITZPATRICK. I don't have any figures on that. I think we might in the department.

Mr. LEWIS. I'm not saying that they have to or they should, I'm just asking you have they ever?

Ms. FITZPATRICK. I don't know. We can check and see if we have anything and supply it for the record.

[The information follows:]

PETROLEUM INDUSTRY RENEWABLE ENERGY RESEARCH

Major U.S. petroleum companies have the resources and long term necessity to pursue sustained renewable energy research and development activities. Several firms are now involved in renewable energy technologies such as photovoltaics, land fill gas, geothermal, and biofuels. The extent to which a portion of their profits are dedicated to specific renewable energy research is privileged information due to competitive considerations and, therefore, is not provided to the U.S. Department of Energy. Factors such as oil supply and demand, technology advancements, and corporate financial health influence how much future efforts and money the petroleum industry will devote to renewable energy research and development. The involvement of these oil companies, and other members of the commercial sector, provides an important source of long-term renewable energy research and development while at the same time complementing and further advancing Department of Energy renewable energy activities.

Mr. LEWIS. Thank you, Mr. Chairman.

Mr. GLICKMAN. Thank you. Mr. Boehlert.

Mr. BOEHLERT. Just one quick question. Does your budget proposal include a 5-percent reduction for your employees?

Mr. COLLINS. Yes, sir.

Mr. BOEHLERT. Where are you going to get the money when we tell you you can't do that?

Mr. COLLINS. I imagine the same place we do for everything else. Eventually, if that was the case, we would have to come back to the Congress with a supplemental request.

Mr. BOEHLERT. Were all departments on order from OMB to do that—to prepare their budgets in a similar fashion?

Mr. COLLINS. I'm under that impression.

Mr. BOEHLERT. Well you've got a tough row to hoe because that ain't gonna happen.

Mr. GLICKMAN. Mr. Packard.

Mr. PACKARD. You're going to have to help me get up to speed on some of the specifics of your budget. What criteria do you use in your budgeting request to delete money from one project like your Stirling engine and include money for other projects?

Mr. COLLINS. Certainly at one point it does get down to a subjective call when you're dealing with industry and trying to determine whether they can take that over at that point in time. Basically, how much basic science is left to be known; how much the industry has done in general; how much they seem to be willing to do. That certainly plays a large role across-the-board in the Department and particularly here. In this instance a couple of companies have evaluated this decision and they could proceed on it. We have five engines that are available for people to have a look at and make a determination as to whether they want to pursue it in the private sector. That is a tough line where you're at proof-of-concept which shows if it really works and what we have proven in the basic science work. Have we done the basic science work and can others pick that up?

It's a judgment call and often a close one. We think this probably qualifies at this point in time, Mr. Packard.

Mr. PACKARD. I presume that we do make available the technology that has been developed on any programs that we are closing out or do not complete. We make those available to any private sector companies.

Mr. COLLINS. Excellent point. We certainly do. The President proposed last year, and we are pleased that the Congress accepted, a 500-percent increase in technology transfer moneys in the conservation and renewable area so that we would have more seminars and more of our staff would be available to share this with the private sector so that they could make a more informed decision on picking it up.

Mr. PACKARD. Thank you, Mr. Chairman. No further questions.

Mr. GLICKMAN. Pat, I don't think we have anymore questions. We appreciate your testimony and appreciate your accelerated testimony, but the content was there—not always agreed to—but presented in good faith.

Mr. COLLINS. Thank you very much.

[The prepared statement of Mr. Collins follows:]

STATEMENT OF

WILLIAM PATRICK COLLINS

UNDER SECRETARY

U.S. DEPARTMENT OF ENERGY

BEFORE THE

COMMITTEE ON SCIENCE AND TECHNOLOGY

TRANSPORTATION, AVIATION AND MATERIALS SUBCOMMITTEE

U.S. HOUSE OF REPRESENTATIVES

FEBRUARY 27, 1985

Mr. Chairman and Members of the Subcommittee, I appreciate the opportunity to appear before you today and provide information on the FY 1986 budget request concerning the Department's energy conservation research and development programs in the transportation area. The budget fully supports the goals and strategies of the Fourth National Energy Policy Plan. I will summarize those parts of the Plan which are relevant to the subject of today's hearing and discuss highlights of the FY 1986 budget.

NATIONAL ENERGY POLICIES AND STRATEGIES

The overall goal of our national energy policy is to foster an adequate supply of energy at reasonable costs. This policy recognizes that "adequate supply" requires flexibility in the energy system, with no undue reliance on any single source of supply. The goal of "reasonable costs" suggests economic efficiency within the energy system, so that energy consumers, individuals, commercial and industrial users alike, are not penalized by economic rigidities introduced into the system by ill-advised governmental regulation. The strategies for achieving this energy policy goal are:

- to minimize Federal control and involvement in energy markets while maintaining public health and safety and environmental quality; and
- to promote a balanced and mixed energy resource system.

The FY 1986 budget implements these strategies by supporting development of a mix of technologies that can contribute to both energy supply and

improved end-use efficiency. In allocating our resources, we are concentrating on applying Federal funds only where they are most effective by sponsoring longer-term, high-risk research and development where the potential payoff is high but which private industry cannot be expected to pursue. The budget continues the Administration's policy of not funding commercialization activities which are the proper province of the private sector.

TRANSPORTATION RELATED GOALS AND OBJECTIVES

The objectives of the Department's energy conservation research and development programs in the transportation area are to contribute to improved energy efficiency and enhanced diversity of available end-use technologies. These programs provide the technology base necessary to support private sector efforts to develop technologies which are either more efficient or serve as alternatives to those based exclusively on petroleum.

The importance of our efforts in this area is underscored by the fact that the transportation sector accounted for 27 percent of total U.S. energy consumption in 1984, and more importantly, 61 percent of U.S. petroleum consumption, up from 51 percent in 1973. During this period, the private sector has made substantial investments in more efficient transportation technology and major improvements have occurred, as evidenced by the fact that the average fuel economy of 1984 model automobiles was 88 percent better than that for 1973 model year automobiles. Nevertheless, further technological improvements are possible in energy efficiency and in fuel flexibility. Our program focuses on

highway vehicles because three-fourths of petroleum use in transportation is by highway vehicles. The remaining one-fourth is used by other modes, including rail, air, and marine.

FY 1986 BUDGET

The FY 1986 budget in the transportation area requests $43.0 million for operating expenses and construction. This amount is required to carry out a comprehensive program of research and development with a number of specific objectives. These are to: (a) establish proofs-of-concepts for advanced engine technology that have at least a 30 percent improvement in fuel efficiency over comparable conventional engines, meet emission, safety, and noise standards, have alternative fuels capability, and have competitive production costs; (b) develop technology for heavy duty diesel operation under uncooled and minimum friction conditions, having the potential of 30-40 percent fuel economy improvement over 1982 technology; (c) advance battery and propulsion system technology for competitive electric and hybrid vehicles for passenger car, van, or light truck applications; (d) establish a fundamental ceramic and advanced materials technology base for heat engines; and (e) develop a utilization-oriented data base on switching from petroleum to fuels made from oil shale, coal, and biomass.

I would now like to describe individually the Department's sub-program activities in the areas under your jurisdiction.

VEHICLE PROPULSION R&D

To achieve the objectives specified in P.L. 95-238, the Automotive Propulsion Research and Development Act of 1978, research and development has been pursued to establish technology bases for three advanced engine concepts, the automotive gas turbine, the automotive Stirling engine, and the heavy duty adiabatic (uncooled, minimum friction) diesel engine. Common to all of these advanced engine concepts is the requirement to develop improved high-temperature materials and components.

The Automotive Gas Turbine (AGT) project has been implemented through cost-shared proof-of-concept engine development contracts with two industry teams. A single-shaft configuration (AGT 101) is being developed by Garrett Corporation/Ford Motor Company and a two-shaft concept (AGT 100) by Allison Gas Turbine Division/Pontiac Motor Division of General Motors. Application of high-temperature structural ceramic components is a critical technology barrier in both concepts because of the high operating temperatures necessary to achieve efficiency goals. Advanced ceramic components are now being integrated into test engines and dynamometer performance characterization of fully ceramicized high-temperature configurations is anticipated by the end of FY 1986. During FY 1985 both industry teams made substantial increases in contractor cost sharing to allow continuation of full engine proof-of-concept development at reduced Federal funding levels. This has allowed both industry teams to complete the integration of ceramic components, both static and rotating, into engine builds at increasing temperatures and power levels. We have requested $15 million in FY 1986 so that both

teams' efforts will be continued with full engine development until completion of the program.

The Automotive Stirling Engine (ASE) project has focused on the development of a proof-of-concept engine with an industry team lead by Mechanical Technology, Incorporated (MTI), combined with United Stirling AB & Company of Sweden. Under this program, transfer of Stirling engine technology to the United States has now been accomplished. Over 8,000 hours of performance testing has been completed on five MOD I experimental engines, and predicted performance goals for the design confirmed. Testing of an Upgraded MOD I (MOD IA) engine, which operates at a higher heater-head temperature and contains much less strategic metal has been completed. The evaluations of the two MOD I engines loaned to industry in FY 1984 have now been completed, and a final design of a MOD II engine which incorporates all of the improvements developed to date will also be completed in FY 1985. All of these designs and data, and the results of the Industry Evaluations, will be transferred to industry for their assessment of the potential of Stirling engine technology for automotive propulsion systems. This transfer of developed technology will accomplish the Federal program goals under our "proof-of-concept" strategy, and therefore we are not requesting additional funds for Stirling engine R&D in FY 1986.

The Heavy Duty Transport Technology project has focused on establishing a technology data base for industry development of uncooled, minimum friction, adiabatic diesel engines. Elimination of the cooling system, with attendant high operating temperatures and recovery of the increased

exhaust heat energy, offers the potential for greatly improved operational fuel economy of 30 to 40 percent compared with 1982 technology. The research strategy has been to concentrate on technology barriers identified by industry and to plan development activities in such a way as to support industry efforts to introduce individual components and concepts. During FY 1985, the program will continue to support component developments on promising ceramic structures and coatings and on solid-lubricants and gas bearings. A single-cylinder engine high-temperature ceramic component test capability will be established, and the development and test of an adiabatic heat transfer model will be continued. In FY 1986 component evaluations of developed ceramic structures in the single-cylinder test cell will be utilized for second stage component developments and a conceptual design for a baseline multi-cylinder proof-of-concept heavy duty adiabatic diesel engine will be carried out with industry. A total of $3 million has been requested in FY 1986 for continuation of the adiabatic diesel project.

Technology Assessment and Transfer activities of the Vehicle Propulsion R&D sub-program will be continued in FY 1986 to provide an ongoing assessment of related private sector developments and other Government-sponsored programs to assure that maximum coordination with industry both for dissemination of research results and gathering of inputs on technology needs is maintained. $2.1 million has been requested for these activities in FY 1986.

ELECTRIC AND HYBRID VEHICLE R&D

The goal of P.L. 94-413, the Electric and Hybrid Vehicle Research, Development and Demonstration Act of 1976, is to develop the technology, in conjunction with industry, that will lead to the introduction of electric vehicles into the Nation's transportation fleet. Because electricity is generated by many different sources of energy such as coal, hydro, photovoltaic, wind, and nuclear (only 5 percent from oil in 1984), the use of electric vehicles would substitute more abundant sources of energy for petroleum-based fuels.

The major emphasis of the Electric and Hybrid Vehicle program continues to be the development of battery technology for vehicle propulsion, with 52 percent of the total program's funding specifically allocated for battery development, testing, and evaluation programs. In FY 1985 the development of electrolyte and thermal control systems of lead-acid and nickel-iron batteries is resulting in improvements in specific energy and cycle life. In FY 1986 complete vehicle lead-acid and nickel-iron battery systems will be delivered and tested that are expected to meet the program's performance goals of a range of 100 miles on a single charge, battery life of 60,000 vehicle miles and acceleration capability better than a diesel vehicle. In FY 1985 sodium-sulfur battery development was initiated, specifically focused on the electric vehicle application and integration with an advanced a.c. propulsion system under development. This development is emphasizing the optimum cell configuration, thermal management, and packaging for the electric vehicle application. The sodium-sulfur effort is based on and closely coordinated with the core technology development by the Energy Storage

Division in DOE's Energy Systems Research Program. The laboratory testing of experimental batteries will continue at the Electric Vehicle Test Center at the Idaho National Engineering Laboratory (INEL), the University of Alabama at Huntsville, and the National Battery Test Laboratory at the Argonne National Laboratory. In FY 1985 the optimum temperature for the performance of flooded and gelled electrolyte lead-acid batteries was determined to be 100°F in the tests over a wide range of temperatures (0° to 130°F). The optimum rate of charging is also being evaluated in laboratory tests. Experimental battery technologies scheduled for laboratory evaluation in FY 1986 include immobilized electrolyte lead-acid, nickel-iron, sodium-sulfur, zinc-bromine, and zinc-chlorine. In FY 1985 a prototype van test bed is being fabricated in a jointly funded Department of Energy/Electric Power Research Institute (EPRI) project to test and evaluate the best available battery and propulsion system technology.

In FY 1985 an advanced single-shaft a.c. powertrain is being completed by the Ford Motor Company that incorporates a unique, sealed, light-weight motor/transaxle assembly and a controller/power inverter using experimental high-current transistors. The system has been installed in a test vehicle and full system operation verified in dynamometer and on-the-road testing. Also in FY 1985 the next generation of the promising technologies under this program will be explored, including improved permanent magnet materials that will decrease the weight and lower the cost of the traction motor and reduce the complexity and cost of the electronic control system. Efforts will continue in FY 1986 on the dual-shaft propulsion system technology development for commercial van

application. The dual-shaft propulsion system incorporates an a.c. induction motor, multi-speed automatic transaxle, controller/power inverter technologies and the nickel-iron battery technology.

Test and Evaluation activities in FY 1985 include the actual on-the-road vehicle site operations that evaluate current-technology electric vehicles in fleet applications, as well as the technical and economic feasibility of new technologies. In FY 1985 the new technologies being evaluated by the Site Operators' User Task Force include advanced lead-acid, nickel-zinc, and nickel-iron battery systems, battery watering systems, transistorized controllers and improved battery chargers. The laboratory testing and evaluation of new electric vehicle technologies, including technology developed outside of the DOE program, is carried out by the Electric Vehicle Test Center at INEL. This unique test facility became operational in August 1984 and has the capability of testing and evaluating recently developed battery, propulsion and complete vehicle systems on a computerized chassis dynamometer under controlled laboratory conditions. Electric vehicle track tests are also conducted by the Test Center for correlation and validation of the laboratory tests. In FY 1985 the Test Center is performing the engineering evaluation of the Eaton a.c. and d.c. powertrains, the GM Bedford electric van, the Soleq a.c. controller, and advanced battery systems (lead-acid, nickel-iron, nickel-zinc) interconnected with test vehicles. In FY 1986 the Test Center will complete the testing of the technologies initiated in FY 1985 and begin the evaluation of nickel-cadmium batteries, the joint DOE/EPRI electric van test bed, and an advanced transistorized controller.

As the development of electric vehicle technologies matures, the transfer of the technology to private industry is an important activity of the program. In FY 1986 a Contractors' Coordination Meeting is planned for electric vehicle users, manufacturers, and the research community to disseminate the results of current development progress and to plan future coordinated R&D efforts. Regional workshops on battery development, testing and maintenance training conducted in FY 1985 have been very effective and will be continued in FY 1986.

The total funding request for the Electric and Hybrid Vehicle R&D program in FY 1986 is $6,075,000.

ADVANCED MATERIALS DEVELOPMENT

Improved materials technology is a key requirement in all transportation propulsion R&D activities. In high performance energy conversion systems, and in particular in advanced transportation engines, operation at high temperatures in corrosive environments is essential for obtaining substantially improved efficiencies. A critical need is the development of ceramic, ceramic composite, or ceramic coated components which can withstand these operational environments. Although the advanced engine projects are providing the required focus to prove the feasibility of ceramic components, they have also demonstrated that a parallel basic ceramics research effort is necessary to assure future development of reliable and reproducible ceramic parts. The goal of the Advanced Materials Development Program, therefore, is to establish an industrial ceramic technology base capable of providing reliable and

cost-effective components for high-temperature, efficient propulsion systems while eliminating requirements for scarce strategic materials.

In accordance with the basic ceramic technology areas identified in the program plan developed through a comprehensive industry assessment, research activities in FY 1985 will include development of improved powders, determination of properties of ceramic composites and coatings; ceramic joining; characterization, processing and densification of green-state ceramics; and statistical concepts for design methodology. During FY 1986 the phased activities on existing contracts and research projects will be continued, and new work on scale-up of improved powder synthesis, composite processing, and life prediction for composite materials initiated. The excellent coordination procedures established with both Government and industry laboratories will be maintained and an industry-university advisory committee for continuing program planning and implementation review is being formalized. We have requested $9.3 million for the Advanced Materials Development Program in FY 1986.

The High Temperature Materials Laboratory (HTML) at Oak Ridge National Laboratory was initiated in FY 1983 to support advanced high-temperature ceramic and alloy materials research in both Government and industry. The HTML will have a unique capability with a broad multidisciplinary professional staff serving as a common focal point for industrial/university/Government participation and having access to high-cost research equipment. During FY 1985 actual construction on the laboratory facility will begin and procurement specifications for major items of research equipment will be released. Building occupancy is

scheduled for 1988. In FY 1986 we have requested $3.0 million for the final increment to complete the building and begin development of operational procedures and research staff requirements.

ALTERNATIVE FUELS UTILIZATION

The goal of the Alternative Fuels Utilization Program is to establish a utilization oriented data base for alternative fuels in both contemporary and advanced heat engines. The approach has been to conduct systematic research on the fundamentals of alternative fuel use in both spark ignition and diesel engines, concentrating on nearer-term fuels first (alcohols) and expanding the data base in subsequent stages to include synthetic fuels and advanced engines.

During FY 1985, basic fuel/engine performance/emissions investigations to identify and provide understanding of engine problems associated with the use of synthetic fuels, and work on methane utilization with primary emphasis on diesel engine data is continuing. The first phase of a Federal fleet methanol-fueled vehicle demonstration is being initiated. In FY 1986 the first phase of the methanol-fueled fleet demonstration will be continued in order to establish vehicle specifications, site locations, data collection and analysis, and fuel stations. Performance, emissions, wear, and optimization investigations on conventional and advanced engines using synthetic fuels and performance investigations on using methane fuel will also be continued. A total of $1.6 million has been requested in FY 1986 for this work.

PROGRAM DIRECTION

To provide the overall program direction of the transportation program including the development of the strategy, plans and resource requirements, and integrated program management, we are requesting $1,700,000 in FY 1986.

SUMMARY

In summary, the activities of the Department's transportation program cover a broad spectrum of projects structured to increase energy efficiency and reduce petroleum dependence in the transportation end-use sector. Although the program is focused on the transportation sector, the technologies under development for high-temperature ceramic materials, gas turbine and Stirling heat engines, batteries, and control systems can be effectively used in many other areas as well as the mobile application.

That concludes my testimony, Mr. Chairman, and I thank you for the opportunity to appear before you today.

Mr. GLICKMAN. Our next witness is Mr. Noel Nightingale, program manager of the Automotive Stirling Engine Program with MTI, and Mr. Bruce Goldwater.

We welcome you here and why don't you proceed to go ahead. Again, we are going to set the bell and why don't you try to stay within that.

STATEMENT OF NOEL P. NIGHTINGALE, PROGRAM MANAGER, AUTOMOTIVE STIRLING ENGINE DEVELOPMENT PROGRAM, MECHANICAL TECHNOLOGY, INC., LATHAM, N.Y.; ACCOMPANIED BY BRUCE GOLDWATER, GENERAL MANAGER, STIRLING ENGINE SYSTEMS DIVISION

Mr. NIGHTINGALE. Thank, you Mr. Chairman. My outline for my summary presentation today, which is really a summary of my written testimony which I have presented for the record, is that I would like to go over some of the program status and emphasize particularly the industry testing and evaluation program that we ran with General Motors and John Deere and the industry and military interest shown in the ASE technology update and similar activities in Japan and China with a set of conclusions and recommendations for you.

Mr. NIGHTINGALE. Basically the major accomplishment during 1984 lay in three areas: MOD II engine and design development; our testing under the ITEP with General Motors and John Deere with MOD I engines; and the continued reliability that we've been able to show through our MOD I engine testing.

Let me dwell a little bit more on the details of that. During 1984 we had a manufacturing cost study and I'll come back to this perhaps in answering why do we want to complete the MOD II. The manufacturing cost of the MOD II study was conducted by an independent company called Pioneer Engineering and Manufacturing, located in Detroit. They are familiar with the automotive industry, and they concluded in June after their study that the MOD II had a competitive cost with diesels and IC engines; that the specific weight was now down in a competitive area with diesels and IC's, both of which the MOD I does not meet. We have started to manufacture some major parts. In fact, I have on the floor here a couple of the parts for the MOD II—mainly the vee block which was cast out in the new manufacturing facility with John Deere—and our annular heater head which is cast from a company in Indiana.

We have established a wide vendor base throughout the United States who are now familiar with Stirling engines all the way from California to Florida to Wisconsin, right across the nation. I think this (fig. 1) graphically shows, because this is to scale, why we're able to manufacture the MOD II and make it competitive and why the MOD I is simply a vehicle to demonstrate the technology. You can see the difference in the size and the corresponding reduction in the cost.

The highlight of the program during the year was our industry testing evaluation program. We gave a MOD I vehicle, the vehicle which is on display down beside this building today, and they tested that vehicle according to EPA procedures on a chassis dynamometer; they tested it in a wind tunnel up to 125°F which is synonymous with their highest specification; and they conducted road tests. I'll be getting into some of that data.

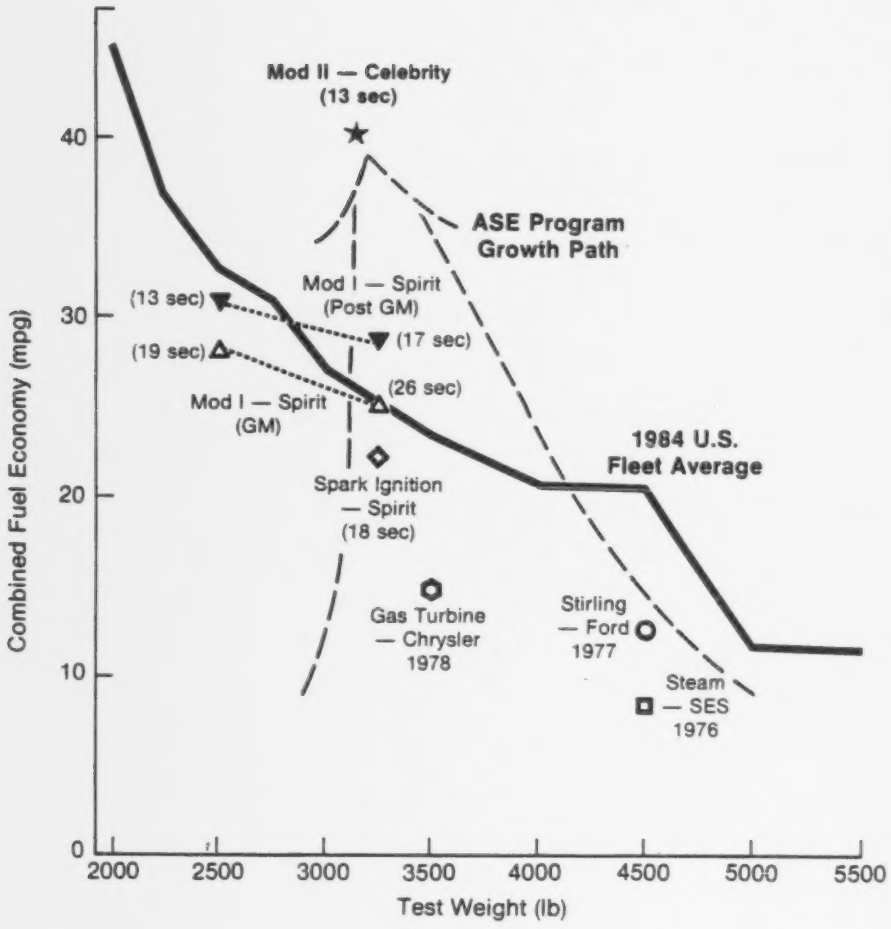
John Deere basically was looking at the engine from a power plant point of view and they did their testing in a static test cell.

I'd like to take a few minutes to explain this curve because this is at the core of my testimony (fig. 2). It's not my curve; it is General Motor's curve. It shows the fuel economy vs. the weight of the vehicle and the dark line is the 1984 U.S. fleet average. This is presented in General Motors' report on the ITEP. When we started off we had a spark ignition Spirit which was an IC engine and gave us about 22.5 miles per gallon. When General Motors tested you must match your accelerations and that corresponded to a vehicle at 2,500 pounds. At that point, General Motors handed the vehicle back to us, told us our idle fuel flow was too high, told us our vehicle matching characteristics were not optimum. Since June, when they told us that, we have raised the line up to the 17-second and the 30-mile-per-gallon point. There are three points to be made on this curve. One is that if you take a look at the gas turbine Stirling and steam which are not my points, you will see that they are about 2½ times higher in fuel economy from the basic technology that we started out with at the beginning of this program.

Secondly, there has been a cross-over in the curve of the program development to the U.S. fleet average.

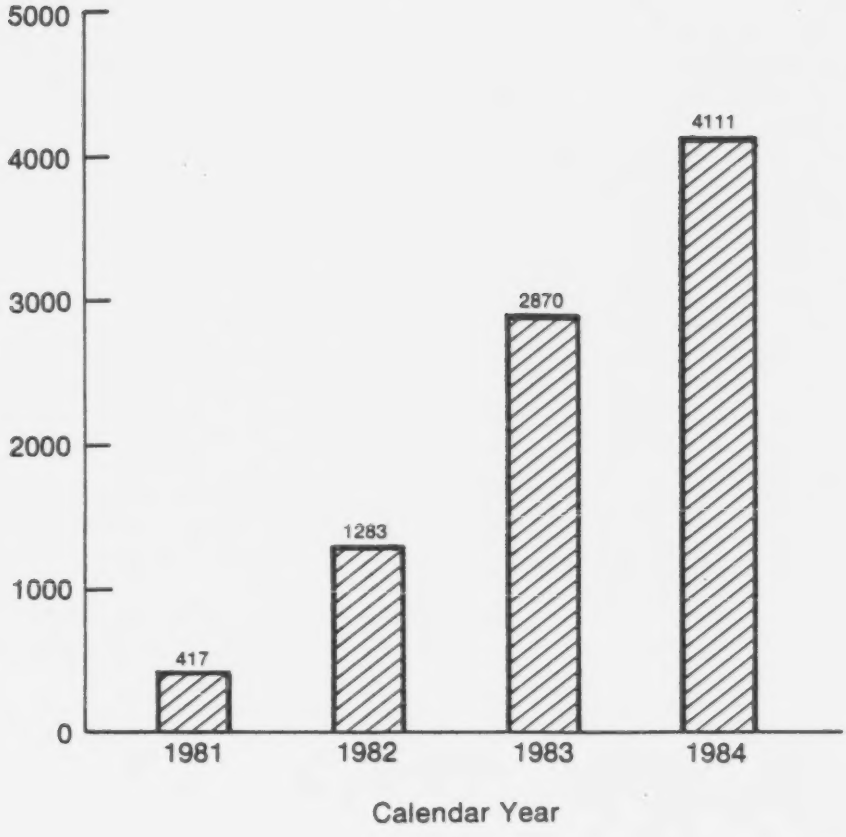
Thirdly, the star at the top is our MOD II projected mileage which is 50 percent above the fleet average. We see no need not to expect that we will achieve that.

Our MOD I continues to perform very reliably. We have seven testing engines now. We have accumulated over 8,000 hours. This is very important to industry as well. This is a graphical demonstration of how we've achieved those hours over the years. You can see that we're demonstrating that reliability as time goes (fig. 3).



Stirling Engine Fuel Economy Comparison

FIGURE 2



Mod I Engine Test Hours

FIGURE 3

I did want to touch upon a little bit of the industry and military interest in the ASE technology. Valmont, which is a leading company from Nebraska in irrigation systems, is very interested in using the Stirling technology coupled with a heat pipe in a fluidized bed. The reason for this is that the irrigation costs for the farmer are 18 percent of the gross crop value—it used to be around 3 percent. By utilizing coal and utilizing the high efficiency of a MOD II engine, they see a savings of $750 million per year in energy costs. That was a concluding number out of a study done for the U.S. Department of Agriculture.

As mentioned earlier, the U.S. Army is very interested in the MOD I and we are currently trying to line up a demonstration with one of the MOD I engines for a 30 kilowatt generator set unit. The reason for that is the quiet operation and its reliability. The Air Force is very interested in using the Stirling engine and they have approached us again for a demonstration program to use on the flight line. In that case, they can use the JP-4 fuel which is the same that they use in the aircraft. The Navy is very interested in the Stirling engine for submersibles. The MOD I is noisy because you have gears, but the vee Mod II has no noise and that is a big advantage to a submarine.

In terms of foreign activity, Japan has started a rather large energy conservation program back in 1982 called the moon light project and as part of that there is a Stirling engine development aspect. It's under the industrial science and technology—the agency. It's about $43 million for 6 years and their demonstration period is in 1987. I've listed here a few of the companies that we know of (fig. 4).

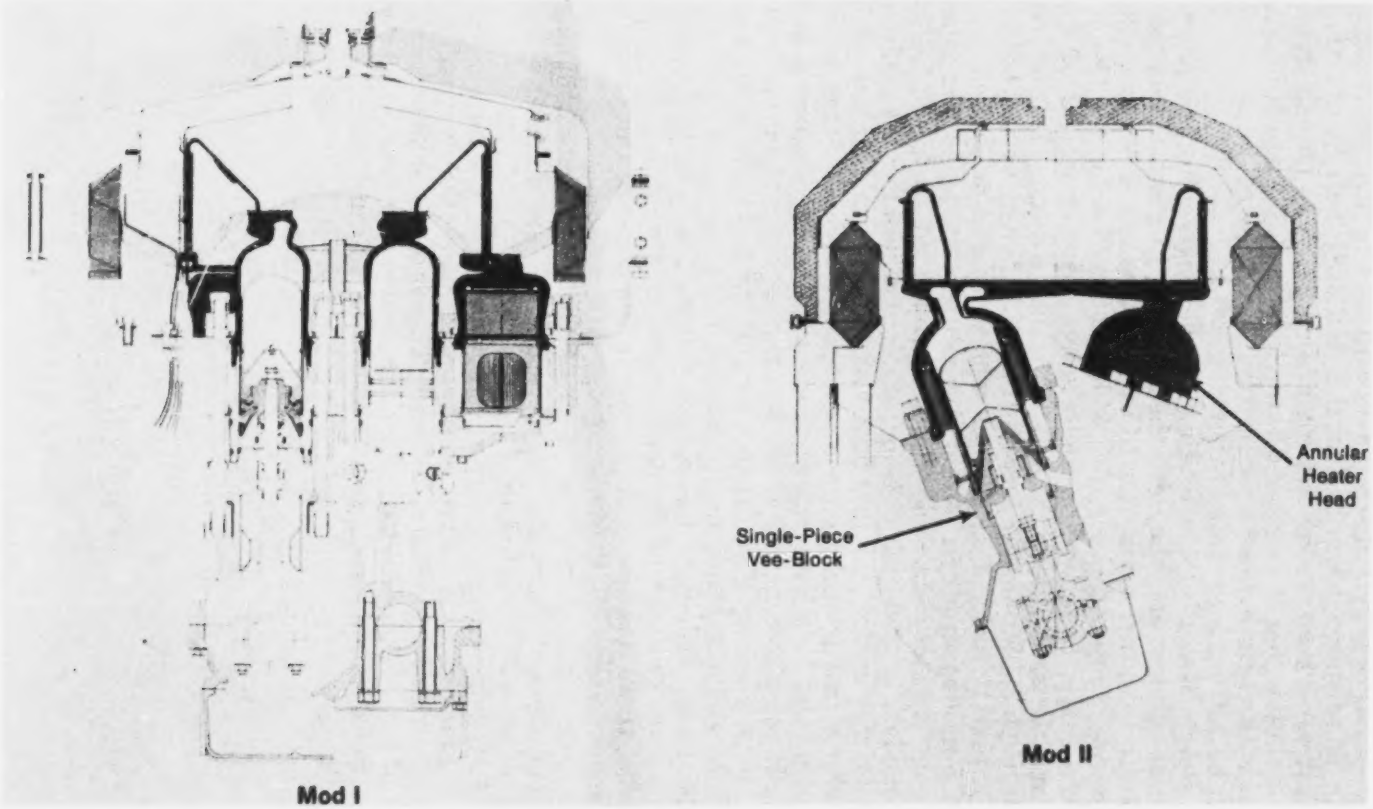
One of the organization charts from a Japanese brochure, shows the applications that they see applying Stirling engine technology that they have kicked off under this Moon Light Program (fig. 5). You can see that, in addition to marine construction and industrial, the automotive application is there and we know that they are going to try and attempt to install an engine very similar to the type we are developing in our program in a Toyota very soon.

Automotive Stirling Engine Development Program

FOREIGN ACTIVITIES

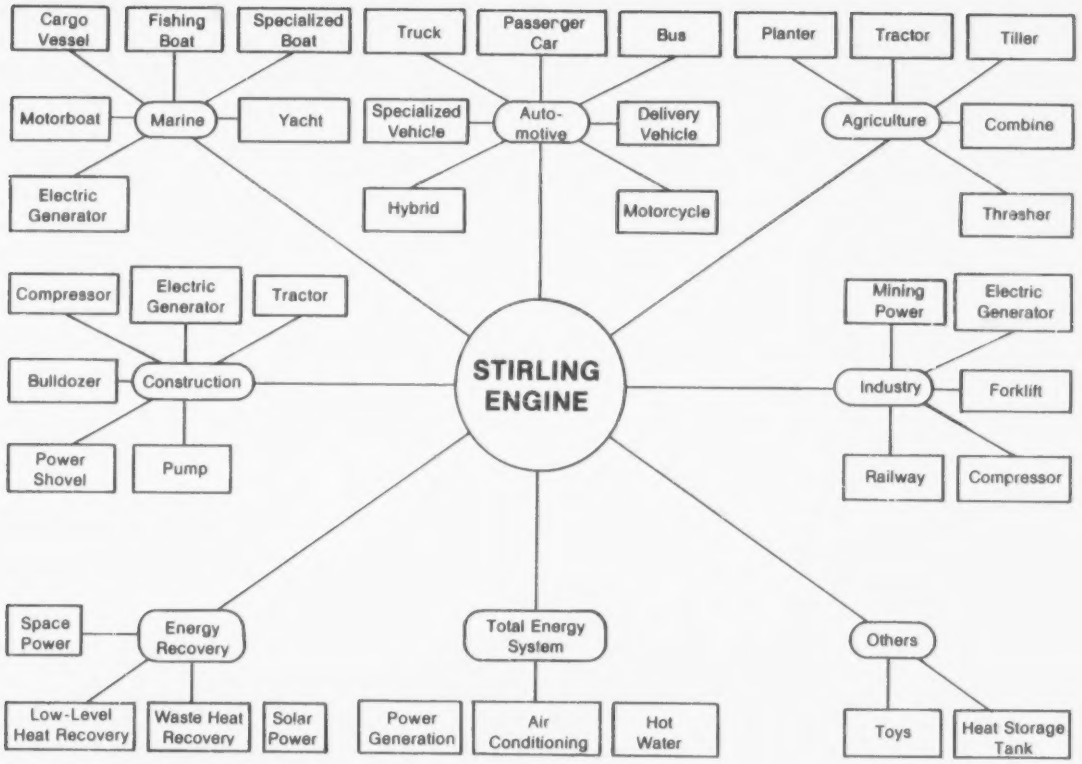
- Japan
  - — Agency of Industrial Science and Technology (AIST)
  - — Part of "Moon Light Project"
  - — Started in 1982; 43 Million U.S. Dollars for 6 Years
  - — Companies
    - o Aisin Seiki
    - o Tokyo Sanyo Electric
    - o Tokyo Sanyo Electric Tokki
    - o Tokyo Shibanra Electric
    - o Mitsubishi

FIGURE 4



Comparison of Mod I and Mod II Engine Cross Sections

FIGURE 1



*Source: Japanese New Energy Development Organization (NEDO) Brochure, 1984

Japanese Stirling Engine Applications

FIGURE 5

There has been quite a lot of interest in China as well for Stirling engines. The reason being, that they do not have electrical grids and they pay a high cost for their diesel fuel such that their urban farmers—which number around 800 million—require electrical power for heating and hot water. They have methane gas from the vegetable and animal residue. The Stirling engine can run on that low BTU methane gas. We have established a program with the Shanghai Marine Diesel Engine Research Institute to develop a 20 kilowatt Stirling engine for production in China for that application. MTI holds all the rights of manufacture and I think this is a great opportunity for new products and new technology in the United States.

I would like to close with a set of conclusions. I think that the MOD II can meet the goals of the Public Law that was established back in 1978. I would certainly endorse your opening comments that the rationale then still applies. I think that, if you look over the long term, the MOD II is going to be there when you call for it and I'm sure that time is coming. We should not be lulled by the low price of fuel today. The MOD II can, in fact, meet the intent of the Public Law. It is on schedule; it is on budget; and it is meeting all of its technical goals.

The ITEP Program was very successful and it has resulted in improved fuel economy in our design approach. I think the Stirling engine offers an excellent technology base from which the United States can establish an economical leadership. The military has shown interest within the last 12 months and that we have developed a team of experts who are in place and can now transfer that technology to industry.

In closing, Mr. Chairman, I would like to make two recommendations to you. One is to continue to authorize the ASE program through to the demonstration of the program objectives of the MOD II. I think that the ITEP program should continue to include the involvement of MOD II engines and to enhance the industry participation.

Mr. GLICKMAN. We've got a vote and we are going to have to leave in a couple of minutes. Let me just ask you a couple of quick questions.

If the project is terminated at the end of this fiscal year, what still remains to be accomplished?

Mr. NIGHTINGALE. The entire demonstration of the program goals. I think we would be where we are today which is that point on that mileage curve which is about 15 percent above the fleet average and an engine which is not manufacturable.

Mr. GLICKMAN. How do you answer the DOE rationale for terminating the Stirling Program—namely that transfer of the MOD I technology to industry will accomplish Federal goals under its proof-of-concept strategy.

Mr. NIGHTINGALE. We've been in to see GM, Ford, and Chrysler and the reaction of those people is not necessarily focused on the performance. It is the manufacturing cost and it is reliability. Until they see that demonstrated in hardware form, I don't think they are going to go for the technology. I don't agree with that rationale at all. I think we have to demonstrate that the engine can be manufactured for competitive prices.

Mr. GLICKMAN. Mr. Lewis.

Mr. LEWIS. What were the evaluations by GM and John Deere? I don't recall you providing those.

Mr. NIGHTINGALE. The evaluation of General Motors was basically that the idle fuel flow of the engine was too high. When you run according to the EPA schedules, in the urban you spend a great deal of time down at idle and that tends to keep your urban mileage down. With a heat engine, it is very difficult to reduce that idle fuel flow. Their observation was that our idle fuel flow was too high. Their other observation was that the engine did not really match the drive train. That's because we are not in the vehicle business. We had built the MOD I to demonstrate the Stirling technology; not to have it match to a vehicle system contrary to what we've done in the MOD II. That was the observation of the General Motors people.

Mr. LEWIS. In your material on the specific cost dollars per horsepower, the upgraded MOD I is down somewhere around 40, where you have the diesel and the MOD II that will meet a goal of 15 by the end of 1985. How do you expect to get from 40 to 15 in that short period of time?

Mr. NIGHTINGALE. If I had a chance to go back to my cross-section—the first problem with the MOD I is that it is a layered design. It's case upon case upon case—it is made up of about five cases when you get up into the combustion system. The MOD II is a single casting block. The other major cost reduction is that the MOD II is an annular heater head. That requires a casting around the cylinder and there's one per cylinder. In the MOD I, there were two castings per cylinder; a lot more metal and a lot more cost.

I think one of the more significant cost reduction areas is, that in the MOD II, we are using the ceramic preheater developed by the Coors Porcelain Co. and in the MOD I, the preheater is made up of about 1,200 single pieces of plate metal—hand-welded. Those three major parts are what drive the cost of the MOD II down to a competitive level. We have also been able to work on the specific power of the engine or specific weight of the engine to bring it down in overall size and weight. The two engines are 60 kilowatt level.

Mr. LEWIS. Gentlemen, we are going to have to recess right now. We have a vote.

[Recess taken.]

Mr. LEWIS. We will reconvene the subcommittee. The chairman will return shortly.

Mr. Nightingale, with the Department of Energy proposal of no funding for this engine for this year, if you do not receive any funding, what will be the next step as far as the Stirling engine?

Mr. NIGHTINGALE. What will we do this year to wind down——

Mr. LEWIS. Are there any cooperative agreements that you could move into if you received no funding or 50 or 25 percent of what you're asking?

Mr. NIGHTINGALE. The areas of interest that I listed in my view graph, each one of them and even together is not sufficient to support the team that we've put together under ASE. I think we would find ourselves in a position that the Stirling activity would basically come to a stop.

Mr. LEWIS. When do you anticipate getting into a cooperative agreement with someone? What year?

Mr. NIGHTINGALE. 1987.

Mr. LEWIS. When would you expect a phaseout of Federal funds?

Mr. NIGHTINGALE. For 1987. We would like to be in a position a year from now to be able to tell you that we have on board some industry participation to complete the MOD II development. Under that, there would be some cost-sharing involved. I think that the ITEP program has opened the door to that possibility—a very real possibility—because I think we have some meaningful data now that we can discuss with General Motors and other companies. We are, in fact, in agreement with GM to retest our Spirit after we've made our improvements for them to see the improvement that has been made in the MOD I.

Mr. LEWIS. This means that if you go into the MOD II and you put those in the Spirit you would be able to have an evaluation?

Mr. NIGHTINGALE. We've putting the MOD II in a GM Celebrity—the five-passenger family car with around 3,100 pound inertia weight.

Mr. LEWIS. Does your evaluation at this point of your performance data indicate that you would need the performance parameters that are outlined with a MOD II.

Mr. NIGHTINGALE. Yes. One very important feedback to us from the ITEP program with General Motors was that all of our code predictions were matched by the data that I showed on that chart. we have been able to predict the performance of the engine and the vehicle fairly accurately. We are using that same prediction modeling for our MOD II and we feel pretty confident.

Mr. LEWIS. With regard to the Stirling, the project actually demonstrated the original 30 percent improvement of fuel efficiency. Would the MOD II do better than this?

Mr. NIGHTINGALE. The demonstration of the 30 percent was not made by the MOD I. The MOD I demonstrated only 15 percent. That was the point on that graph that was about 15 percent higher than U.S. fleet. The MOD II is projected to be 50 percent above the fleet average which is well above the goal of 30 percent.

Mr. LEWIS. Will you describe for the record your discussions with Army officials with regard to the engine?

Mr. NIGHTINGALE. In terms of the Army people, they are very interested in the fact that we have an engine that will be quiet and have a low IR signature, in other words, the temperature of the exhaust gases are low, emissions are low, and so it is not detectable by enemy surveillance. Plus the fact that it is a multifuel engine. It is the quietness and the low detectability that is the attractiveness. They always insist that it be a powerplant that has been developed commercially. In other words, that it does have a reasonable manufacturing cost. In our discussions, they are attracted by the MOD I technology, but their ultimate goal is to see the MOD II in the product line.

Mr. LEWIS. How do you answer the DOE's rationale in terminating the Stirling Program?

Mr. NIGHTINGALE. I understand the rationale. The rationale is if you show to industry through proof of concept that a technology is worthwhile, when you show them the performance, and I would

say that MOD I has done that to a certain extent, that that is enough. We've been peddling this business for a number of years and that is not enough. The automobile industry has been burned by the Proco engine, the diesel engine, the 8-6-4-cylinder, the early Chrysler engine, and they want to see reliability and they want to see low manufacturing costs as well as the performance bogey. My rationale is that there are other ingredients which are as important as the performance.

Mr. LEWIS. I don't believe we have anymore questions for you gentlemen. I thank you for coming.

[The prepared statement of Mr. Nightingale follows:]

HEARINGS ON DOE TRANSPORTATION PROGRAMS

Subcommittee on Transportation, Aviation, and Materials
Committee on Science and Technology
U.S. House of Representatives

Presented by: Noel P. Nightingale
Program Manager
Automotive Stirling Engine Development Program

February 27, 1985

Noel P. Nightingale

Mr. Noel Nightingale is the Program Manager of the Automotive Stirling Engine Development Program. Mr. Nightingale is employed with the Stirling Engine Systems Division of Mechanical Technology Incorporated, Latham, New York, a high-technology research, development, and manufacturing company. He has been involved in the ASE Program since its inception in 1978 and has authored various papers on its progress. Prior to that, he was employed for more than twelve years with Pratt & Whitney Aircraft, a Division of United Technologies Corporation. During that period he undertook technical and managerial roles in the design, analysis, and development of military and commercial gas turbines and large (100 MW) ground power units. He also has management experience in multi-national consortium programs and aircraft maintenance. Mr. Nightingale holds a Bachelor Degree in Mechanical Engineering from the University of Toronto and Master Degrees in Engineering Science and Business Administration from Rensselaer Polytechnic Institute.

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TESTIMONY ON THE AUTOMOTIVE STIRLING ENGINE DEVELOPMENT PROGRAM

before

Subcommittee on Transportation, Aviation, and Materials

Committee on Science and Technology

U.S. House of Representatives

Mr. Chairman, members of the subcommittee, my name is Noel Nightingale, and I am the program manager of the Automotive Stirling Engine (ASE) Development Program which is funded and managed by the Department of Energy (DOE). The NASA-Lewis Research Center located in Cleveland, Ohio, is responsible for the project management of the program. The program is being conducted within the Stirling Engine Systems Division (SESD) of Mechanical Technology Incorporated (MTI). MTI is a high-technology research, development, and manufacturing company located primarily in the state of New York, with wholly owned subsidiaries in Michigan and California. The SESD engages approximately 120 people in the development of Stirling engines for a variety of applications. This team, primarily professionals, was formed by MTI in response to the national need for an advanced energy-efficient technology, in this case, the Stirling engine.

Mr. Chairman, MTI appreciates the opportunity to appear before this subcommittee to testify on the ASE development program. It is my pleasure to report that the ASE program continues to achieve its technical goals, while remaining on schedule and within budget. The requests made by Congress have been met and the program is on target for the development of a Mod II engine and the final demonstration of the overall program goals. My testimony reports on the status of the two basic goals of the ASE development program:

- Develop the Stirling engine for automotive application
- Transfer Stirling engine technology to the United States.

In addition, I shall comment on the results of the Industry Test and Evaluation Program (ITEP) with General Motors and John Deere, on the increased interest in Stirling engine technology by industry and the military, on foreign development activities and their possible threat to our industry base,

and on proposed development activities after completion of the ASE program. I shall close with a set of conclusions and recommendations regarding Stirling engine technology. All figures or tables referenced in the text are included, for your convenience, in numerical order at the end of this testimony.

BACKGROUND

In Section 302(b) of Public Law 95-238, the United States Congress charged the DOE with initiating programs leading to the development of advanced automotive propulsion systems. DOE selected two basic engine cycles: the gas turbine and Stirling. The Stirling engine was selected because of its intrinsic capability to provide high cycle efficiency; i.e., when installed in an automobile, the Stirling engine can attain a higher fuel economy than that of conventional power systems. Further, since the engine uses a continuously burning external combustion system, it is capable of using a variety of liquid fuels while maintaining low emission levels.

MTI is the prime contractor on the program, with United Stirling of Sweden (USAB) as a major subcontractor. USAB provides a strong background in Stirling engine technology, and their participation in the program has served to ensure the successful transfer of Stirling engine technology and know-how to the United States.

The logic set forth in the program was to develop two experimental engines in sequence. The first engine, the Mod I, was a new engine design, based on USAB Stirling engine technology as it existed at the beginning of the program in 1978. The second engine, the Mod II, was to be designed in the United States, and was to incorporate technology advancements made during the course of the ASE program. The program is currently in a transitional phase as emphasis has shifted from the Mod I to the Mod II engine.

The ASE program has a number of specific objectives stemming from the public law. They are:

* A 30% improvement in fuel economy over a comparable production engine

- Operation within projected 1985 emissions standards ($NO_x \leq 0.4$, HC ≤ 0.41, CO ≤ 3.4 grams/mile, and particulates ≤ 0.2 grams/mile)
- Interchangeable operation on a variety of liquid fuels
- Reliability and life expectancy comparable to commercial engines
- Initial cost and life-cycle cost competitive with conventional engines
- Acceleration suitable for safety and consumer considerations
- Noise and safety characteristics meeting the 1984 Federal Standards

Although the time frame and magnitude of the ASE program have been altered by budget restrictions over the past years, progress toward the goals and objectives has not waivered. The procurement of Mod II hardware has begun. Testing of the first Mod II engine will begin late in calendar year 1985. This schedule is consistent with recommendations made in the past by this subcommittee. Fiscal year 1986 will be devoted entirely to the testing and development of Mod II engines in order to demonstrate the program objectives by the end of September 1987. Figure 1 depicts this schedule. It is requested that an authorization of 16 million dollars for fiscal year 1986 be allocated for the ASE program.

BENEFITS OF THE ASE PROGRAM

To achieve national acceptance, an automotive Stirling engine must be capable of being packaged under the hood of current vehicles. It must also be able to provide sufficient power to propel a five-passenger vehicle and still meet demanding performance criteria, such as acceleration from 0 to 60 mph in 15 seconds. The engine must be efficient over a wide range of power and speed conditions, providing high fuel economy both in the stop-and-go-environment of city driving and in the constant-speed cruising of highway driving. It must not pollute, and it must be capable of using alternative fuels. It must be inexpensive to manufacture and capable of being serviced (routine maintenance) by the general public. Finally, a Stirling vehicle must be capable of

operation in hot and cold climates while providing the passengers an environment that is comfortable in terms of temperature, humidity, noise, and vibration.

The decision by Congress to develop the Stirling engine for the automotive application, as opposed to other applications, continues to reap suitable rewards. Although the level of technology required to develop an automotive Stirling engine is very high and the goals difficult to achieve, the ultimate benefits will be in proportion to the difficulty of achieving these goals. Moreover, once the ASE goals are achieved, there are almost immediate windfall benefits to other Stirling applications. Examples include generator sets, irrigation pumps, solar electric, heat pumps, industrial prime movers, marine, submarine, and farm equipment. This assessment, although subjective, underscores a key national benefit - that the ASE program will provide the United States with a core technology that has a host of spin-off applications. This, in turn, will provide our nation with the additional capabilities of not only conserving energy in other crucial applications but also of maintaining the technological leadership in those areas. The benefit is already beginning to be realized, since the Army, Navy and Air Force have shown interest in using Stirling engines for military generator sets, submarines and utility vans, respectively. Commercial interest in using Stirling engines for irrigation purposes has also been expressed.

The introduction of Stirling technology into the U.S. implies a vast potential for new jobs related to new products, their manufacture and service, as well as an increase in associated trade employment. The multifuel capability of the Stirling engine will provide personal and national security in times of petroleum dislocation. The Stirling engine will meet the emission standards defined in the Clean Air Act, thereby contributing to the national effort to upgrade our environment. The ASE also provides an advantage to improving our noise environment, as the noise level emitted from a Stirling engine is much lower than that of conventional engines... a Stirling engine requires neither a catalytic converter nor a muffler. Finally, the overall potential for conserving valuable fuel resources through the use of more efficient Stirling engines in automobiles and in other applications is immense.

1984 ACCOMPLISHMENTS

Progress during 1984 was made in three major areas. The Mod II engine design and technologies were further refined and developed. An important test and evaluation program of the Mod I Stirling engine was conducted by General Motors Research Laboratory and John Deere; and, finally, Mod I engines continued to test successfully, yielding valuable durability and reliability information. A more descriptive summary of each area is provided in the following paragraphs.

Mod II Engine

The Mod II engine was designed to meet the program objectives of providing a highly efficient power plant with a competitive manufacturing cost. During the past year, an independent study was made of the manufacturing cost of the Mod II. The study was conducted by Pioneer Engineering and Manufacturing Company of Detroit Michigan, a highly respected company in the automotive industry. Their report contained a detailed cost breakdown for the basic engine, auxiliaries and vehicle integration components. A life-cycle cost analysis, which compared the Stirling engine to spark ignition and diesel engines, was also included. Their overall conclusion was that the Mod II was cost competitive with spark ignition and diesel engines. This factor, coupled with the lower weight and higher efficiency of the Mod II, makes the engine a viable alternative power plant to existing systems.

To emphasize the impressive reduction in size and, therefore, weight and cost in the Mod II, Figure 2 compares the engine cross section of the Mod II to that of the Mod I. Figures 3 and 4 depict the reductions made in the specific weight and manufacturing cost, respectively, of the Mod II to make it competitive with existing power plants.

Two of the major parts in the Mod II that contribute to its lower cost are the single-piece vee-block casting and the annular heater head casting. These parts are identified in the cross section in Figure 2. During the past year, each of these components has been manufactured and developed using United States vendors. The single-piece vee-block was cast by a Wisconsin vendor. A

photograph of a machined casting is provided in Figure 5. Plans are now being carried out to develop castings at a modern manufacturing facility at John Deere. The machining of the castings at John Deere is also being planned. The annular heater head, a photograph of which is shown in Figure 6, was cast by a company in Indiana. Mod II components have been under development throughout 1984 and have now been designed to their final configuration for the Mod II engines.

The manufacture of Stirling engine hardware under the ASE program has required the support of a host of companies throughout the U.S. Although the cost to produce the limited number of prototype parts needed in the program is quite high, there are three important compensating side effects. First, the vendors have developed the skills and understanding necessary for the proper manufacture of Stirling engines. Second, the critical tooling, which in some cases exceeded a cost of $100,000, is in place, which means that there would be no lengthy delays for the procurement of additional hardware. Third, the need for the hardware has had a positive impact on the labor force. Table 1 illustrates the magnitude of the vendor base already established in the U.S. to manufacture Stirling engine hardware.

Industry Test and Evaluation Program

Due to the foresight of this and other Congressional subcommittees, the Industry Test and Evaluation Program (ITEP) was initiated in fiscal year 1983. The ITEP was directed at providing two engines for industry to test, evaluate and assess the applicability of Stirling engines. General Motors, John Deere Company and the Cummins Engine Company all signed formal agreements with NASA/Lewis to participate. The first engine packaged in an AMC Spirit was delivered to General Motors Research Laboratories (GMRL) in April 1984. A photograph of the vehicle is shown in Figure 7. General Motors tested the vehicle on the road; in a wind tunnel, with temperatures as high as 125°F; and on a chassis dynamometer, according to the EPA Urban and Highway procedures. More than 1,082 miles were logged on the vehicle during these tests. A second engine was prepared and shipped to John Deere in August 1984, where it was evaluated in a test cell. Cummins' role in the ITEP was to keep abreast of the test results obtained at each test site.

In both cases, the engines proved to be reliable and experienced no failures. A summary issued by GM of the test results stated that "The reliability of the Stirling engine system was remarkable during the 54.7 hours of testing".

Prior to the GM test program, an AMC Spirit vehicle equipped with a spark ignition engine was tested according to EPA procedures, yielding a combined mileage of 22.5 mpg. The spark ignition engine was then removed from the Spirit, and the first ITEP Mod I Stirling engine was installed in the same vehicle. When tested, the Mod I yielded a combined mileage of 25.5 mpg which is a 13% improvement; however, acceleration times were not the same for both engines. The Spirit vehicle with the spark ignition engine required 18 seconds to accelerate from stop to 60 miles per hour, whereas the Mod I equipped Spirit required 26 seconds. These results indicated that the Mod I engine was underpowered for the 3,250-lb Spirit vehicle. It was General Motors' judgement that the power level of the Mod I more closely matched the power level of a lighter vehicle, such as their 2,500-lb Chevette vehicle. At this test weight, the Mod I Spirit vehicle required basically the same time to accelerate from stop to 60 miles per hour as the Chevette equipped with either a spark ignition engine or a Mod I engine.

Figure 8 is a combined mileage curve for the United States vehicle fleet average for various vehicle weights. This curve, provided by GMRL in their report submitted under the ITEP, points up the well-known fact that lighter vehicles provide higher mileage. Of particular interest on this curve is the mileage of the Mod I Spirit measured by General Motors at test weights of 3,250 lb and 2,500 lb, with the acceleration time between stop and 60 mph shown in brackets. When compared to the GM Chevette (at 2,500 lb), the mileage of the Mod I Spirit was 15% lower. The General Motors test results indicated that the idle fuel flow was too high and engine powertrain matching characteristics were not optimum. Since the General Motors tests, important changes in these two areas were made to the Mod I Spirit in response to the GM evaluation. The Spirit was retested and yielded higher mileage and better acceleration time. It should be noted that all of these changes are technologies designed into the Mod II engine and vehicle system.

The results of these improvements are reflected on Figure 8. The mileage at 2,500 lb increased to 31 mpg, a level almost equal to the Chevette and the U.S. fleet average. However, acceleration improved to 13 seconds, making a comparison at 2,500 lb inappropriate. A comparison at 3,250 lb is appropriate since the acceleration at that weight was 17 seconds, which is comparable to the original spark ignition Spirit and the U.S. fleet average. The mileage at 3,250 lb is 30 mpg, which is 18% above the fleet average. The purpose for this comparison is to underscore the valuable contribution GM made in evaluating the Mod I Stirling Spirit. GM supported the tenet that fuel economy figures can be compared only after first matching acceleration times. Moreover, GM provided a technical critique which was understood and accepted by our engineering staff. In response, we incorporated improvements in the areas pointed out by GM, and the Spirit mileage and acceleration time improved to the point where the Stirling is above the U.S. fleet average at 3,250 lb with comparable acceleration. This type of industry input is extremely valuable to the success of the ASE program and will be pursued.

GM also included in Figure 8 mileage figures for other alternative powerplants of the past - 1976 steam (SES), 1977 Stirling (Ford) and 1978 gas turbine (Chrysler). For comparison purposes, the Mod II fuel economy has been added to this figure. The Mod II is projected to have an acceleration time of 13 seconds and a combined mileage of over 40 mpg when installed in a GM Celebrity vehicle in the 3,125 inertia weight class. The Mod II fuel economy will be 50% above the U.S. fleet average. The growth path pursued by the ASE program is shaded over the figure to emphasize the advancement made in Stirling technology. It is worth noting that the progress made in the state of technology since 1977 points to a crossover that has occurred between the U.S. fleet average and Stirling technology. Demonstration of the Mod II fuel economy will, in fact, show the superiority of the Stirling engine in the automotive application as compared to conventional technologies reflected in the U.S. fleet average curve.

Stirling Engine Reliability (Mod I)

During the past year, seven Mod I engines have undergone active development testing, bringing the total accumulated test hours to 8,681 by the end of

1984. Figure 9 shows the number of test hours accumulated each year. If industry is expected to accept Stirling engine technology for their product lines, they must be convinced of the engine's reliability through test hours. Warranty claims and maintenance costs are prohibitively high when a product is found to be unreliable. This point represents one of the arguments for keeping Mod I engines under active test in the ASE program, that is, for the sake of industry involvement.

In spite of the attractive performance expected from the Mod II, performance is only one of many issues addressed by industry. Reliability and durability are of equal importance. Funding levels allow the manufacture of only three Mod II engines between now and the end of the program in September 1987. It is anticipated that no more than 1500 hours will be accumulated on these engines during the time frame of the program which is insufficient for industry acceptance. It behooves us to continue to support and test the Mod I engines built under this program to demonstrate the reliability and durability of the Stirling to industry.

INDUSTRY AND MILITARY INTERESTS WITHIN THE UNITED STATES

Mr. Chairman, during the course of this program, we have gained notice and respect from the automotive companies in the United States. Their reaction has changed from negative to positive interest - yet without commitment. This is understandable and should not be construed in a negative sense. It is an expected reaction. It is an extremely difficult task to commercialize an innovative engine in the automotive marketplace. The American public is accustomed to highly dependable and reliable vehicles and is unwilling to put up with the vagaries of a new engine concept.

Over the past twenty years we have seen Chrysler attempt to introduce turbine-driven cars; Ford, Proco engine-driven cars; and General Motors, rotary Wankel, multi-cylinder 8-6-4 engine and diesel-driven cars. In all cases, early operational uncertainties drove these options from the marketplace. As a result, we see more and more American automotive companies purchasing new engine options overseas after they have been tested and proven in foreign markets supported by foreign government research and development

funds, rather than attempt a new concept in the U.S. marketplace. Therefore, in spite of the success of the Stirling, the reason the automotive industry is reluctant to enter into a new engine technology like the Stirling is readily apparent. The ASE program has not yet demonstrated the 30% fuel economy goal, nor has it presented an engine in hardware form that can be manufactured at a competitive cost. Until these goals are demonstrated, it is unlikely that industry will become actively involved. The Mod II is directed at achieving this milestone.

During the past year there has been a steady increase in interest by non-automotive organizations. One company, Valmont, located in Nebraska, is the leading U.S. manufacturer of mechanized irrigation systems. Although they have invested more than $4 million in Stirling engine development, the technology level demonstrated in the ASE program has prompted their interest in the Mod II for a product. The annual consumption of resources for irrigation systems is over 257 trillion Btu, over 2 billion gallons of diesel fuel, 118 billion cubic feet of natural gas and 21 billion kilowatt-hours of electricity. Pumping costs per gross crop value rose from 3% in 1973 to 18% in 1980.

Therefore, fuel efficiency represents a sizeable advantage to the economics of a portion of the farming community. By using inexpensive coal, burned in a fluidized bed, a Stirling engine can be operated through the energy transferred by a heat pipe. The Stirling engine, in turn, would pump the water from the ground and propel the irrigation system to pass over the crops. A schematic of this application is shown in Figure 10. It is projected that a Stirling engine system would be considerably more efficient than existing systems and it would make use of a less expensive resource - coal. It is estimated that more than $750 million per year in irrigation costs could be saved in this industry that has over 80,000 mechanized systems and 509,500 pumping plants that irrigate over 61 million acres.

The military has also begun to show interest in the many positive features of the Stirling engine. The Army, for example, has active programs underway using Stirling engines as the power source for 3-kW and 5-kW generator sets. They have recently shown an interest in evaluating a Mod I engine from the ASE program in a 30-kW generator set. The use of the Mod I engine will provide a

demonstration of the potential gains to be made in using a Stirling engine prior to the availability of the Mod II. The Mod II, of course, is the preferred engine, since it has the more attractive manufacturing cost as well as higher performance. The Army is interested in the Stirling engine because it can use diesel fuel, yet run quietly, with accompanying low emissions and high efficiency.

The Air Force, on the other hand, is interested in using a Mod I engine to demonstrate its advantages for use in a service van. Air Force vans spend a great deal of time at idle while maintenance crews service aircraft on the tarmac. The attractiveness of the Stirling is that it can use JP-4 fuel; therefore, it offers the Air Force a van that uses the same fuel as their aircraft. Again, the long-term goal would be to use the Mod II because of its lower manufacturing cost, fewer parts to reduce maintenance costs and higher efficiency, particularly at idle.

The Navy is interested in the use of the Stirling for submersible units. The main attractiveness is the low noise level. Although the Mod I engine is quiet, it exhibits gear noise because of its two crankshafts that are geared to a single output shaft. The Mod II, on the other hand, is a vee-engine with only one shaft, and it is projected to have lower noise levels than the Mod I or any other nonmuffled engine.

The interest shown by the military is, indeed, encouraging and provides an incentive for continuing the Mod II program. Interest is expected to increase as the technology is better understood throughout the armed forces. It should be noted that all three activities were initiated within the past fifteen months.

STIRLING ENGINE DEVELOPMENT PROJECT IN JAPAN

Nearly 70% of the primary energy requirements in Japan rely on imported petroleum. Although the supply and demand for oil is currently stable, the long-range scenario for a stable supply is doubtful. The development of new nonpetroleum engines and the technical development of energy-conserving equipment has been recognized as necessary. A large-scale Japanese research

and development project entitled "Stirling Engines for Wide Use" was set up and started in 1982. This was part of an energy conservation program named "Moon Light Project" at Japan's Agency of Industrial Science and Technology (AIST), Ministry of International and Trade Industry (MITI). Total funding is nearly 10 billion yen (43.5 million U.S. dollars) for the six-year Stirling engine development effort slated through fiscal year 1987.

The Stirling engine project objective is to realize 3-kW and 30-kW class engines with better fuel economy, fewer pollutants, lower noise emissions and multifuel capability. The engine test demonstrations are to be made in fiscal year 1987 for use in power plants of heat pump systems to heat and air condition both residential and commercial buildings and electric power generation.

Four types of candidate Stirling engines are presently under development. A 30-kW swash-plate engine for a commercial heat pump system, designated NS30A, is being developed at AISIN SEIKI Company, Ltd., one of the project contractors. A four-cylinder, 30-kW, crank-drive engine, designated NS30S, is being developed jointly at Tokyo Sanyo Electric Corporation and Tokyo Sanyo Electric Tokki Company Ltd. for use in a compact electric generator unit. Both these engine types use technologies similar to those developed in the ASE program, such as seals, heat exchangers, combustors, drive system and control systems. Two other engine systems at a power level of 3 kW are being developed for use in residential heat pump systems. Designated NS03T and NS03M, these engine types are being developed by Tokyo Shibanra Electric Corporation and Mitsubishi Electric Corporation, respectively.

Figure 11 shows the project organization and the research and development approach of the Japanese program under AIST. Although the four Stirling engine types cited above are intended for three specific applications, it is evident that the New Energy Development Organization (NEDO) is evaluating other applications. Figure 12 is a copy of a brochure released by NEDO showing the applications contemplated for Stirling technology. It is interesting to note that the automotive application is included and strategically placed on the chart. It has been learned that a Stirling engine will be installed in a Toyota vehicle as one of the contractor special accounts within NEDO.

STIRLING ENGINE DEVELOPMENTS IN CHINA

China covers a vast land and is rich in energy resources. Since the founding of the People's Republic of China (PRC) in 1949, the energy industry in China has grown rapidly. Although annual consumption of coal is over 600 million tons, the known deposits of coal are sufficient to last for hundreds of years. In parts of China the consumption of petroleum products is escalating, while in vast areas of the country national utility electrical grids are unavailable. The transportation of fuels for wide distribution is difficult. The goal in China, then, is to utilize the available fuels locally without the need for large-scale capital investment, which creates an opportunity for the use of Stirling engines.

There are approximately six million methane wells in China, and the number is expected to increase in the near future. Straw, together with animal and vegetable waste, is used to generate methane gas. The Stirling engine offers the advantage of burning this low-Btu methane gas to generate electricity for use in these small rural communities. The goal is to provide electricity for cooking and heating to the more than 800 million people living in rural China, so that they do not have to burn straw or methane gas directly. Since many coal mines exist within the large rural area, the operation of Stirling engines on coal is also under consideration.

A Stirling engine development program was launched in 1980 at Shanghai Marine Diesel Engine Research Institute (SMDERI) to design and develop Stirling engines. A Stirling engine product development program for a 20-kW generator set was initiated by a United States company, the result of which is licensed to SMDERI in China. This company, in turn, contracted MTI to design and furnish the engine. The objective is for SMDERI to begin production of engines in China within five years. Other applications under review for this engine include houseboat transportation, coal-fired locomotive and marine applications, and solar electric power generators.

It should be emphasized that this technology has been licensed to SMDERI solely for use within China. All rights to the engine for the rest of the world reside in the U.S. with MTI. Therefore, the resulting product can be

manufactured in the U.S. for sale and distribution by MTI alone, or in partnership with other American companies. This represents a significant product opportunity for the U.S.

POST MOD II

Following the completion of the ASE program, the Mod II will have demonstrated the potential to meet the exacting requirements of the automotive application. However, before any new product is ready for production there are many preproduction phases to pass through. Any preproduction phase would require that industry take the leading role. Manufacturing cost reduction programs would certainly have to be initiated, but these could not be conducted without current knowledge of the technology. Therefore, a period of technology transfer would be necessary. Reliability tests would also be required, which would call for the manufacture of many Mod II engines to be assembled and tested according to various criteria used in the industry to establish reliability and confidence in a product's durability.

The ASE program, proper, should continue to address several major areas. There will be a need to transfer Stirling engine technology to industry which is a multifaceted task. Designers and analysts must be schooled in the characteristics of the Stirling engine. The types of analysis and codes necessary to execute a design would have to be shared. The techniques in assembling and testing the engines would have to be learned. Of more importance, the characteristics of the engine would have to be taught to enable technicians and mechanics to diagnose problems.

Any follow-on to the ASE program should include additional development in the use of alternative fuels. Although the Stirling engine is a multifuel engine, the subtle changes necessary in the hardware have not been totally assessed.

The Mod II offers the potential for using ceramic materials to a larger degree than called for in its current design. After the development of the initial Mod II, this potential should be pursued more vigorously. There are efficiency gains to be made if ceramics are to be used in critical areas of the

engine. As yet, the materials and the design sophistication are not available.

And finally, the Stirling engine, if it is ever to be fully accepted by industry, must be studied in light of all the possible power sizes necessary for many product lines. The automotive application is a very broad field, indeed, and the ASE program engine demonstration is only one point in a vast array of power and application mixes. It would be necessary, after Mod II, to study and design families of engines in coordination with industry to apply the design concepts and technology of the ASE program to the industry product mix.

CONCLUSIONS

Mr. Chairman, I would like to summarize with the following conclusions:

1. The Mod II Stirling engine can meet the original goals of Title III of Public Law 95-238.

2. The Industry Test and Evaluation Program, initiated and supported by this subcommittee, was highly successful and well managed by NASA-Lewis. The ITEP program underscored the technical advances made in Stirling technology over the course of the ASE program. The Mod I engine which was not designed for an automobile in particular, but rather to develop Stirling technology, compared favorably with the U.S. vehicle fleet average when installed in an automobile.

3. The demonstration of Stirling engine technology is not the only criterion used by industry to evaluate whether or not to become "involved". Manufacturing costs and reliability are two additional criteria that are viewed equally as important, or perhaps more important, than a technology that proves high performance.

4. The ASE program continues on schedule, while meeting critical technical goals requested and funded by this subcommittee.

5. Stirling engine technology provides a technological base from which the United States can maintain leadership in domestic and foreign automotive markets, as well as in markets evolving from numerous spin-off applications. The attention and support given by foreign governments and industries to Stirling engine technology threaten the economic leadership of the U.S.

6. There are many possible applications for Stirling engine technology in the military, as evidenced by the interest already shown by the Army, Navy and Air Force. Reasons cited for this interest include low noise, multifuel capability, low emissions, high efficiency, potential for long life and potential for reduced maintenance costs.

7. Stirling engine technology has been successfully transferred to the United States. As a result, a dedicated team of professionals is in the process of translating this knowledge into programs; for example, the China product, military applications, and the irrigation application. Without the continuation of the Mod II engine development and the support of the U.S. Government, the success of these first-step spin-off programs would be compromised.

RECOMMENDATIONS

With the foregoing conclusions in mind, Mr. Chairman, I would like to recommend that:

1. The ASE program be authorized to continue through to the completion of the Mod II engine development. The numerous advances realized to date and those yet to be realized will be lost unless the Federal Government is willing to provide continued support to the program.

2. The Industry Test and Evaluation Program (ITEP) be continued to include additional tests at the sites of automotive companies with automobiles from their product line. If continued, the ITEP should allow for individual companies to conduct independent manufacturing cost studies of the Mod II engine.

Thank you, Mr. Chairman, for this opportunity to appear before this important subcommittee. I would be pleased to answer any questions at this time.

TABLE 1

VENDORS MANUFACTURING STIRLING ENGINE HARDWARE

ALABAMA
- Speed Ring

CALIFORNIA
- Bourns Instruments
- Coulter Steel & Forge Co.
- Bell & Howell
- Kyowa Metriseal

COLORADO
- Coors Ceramics

CONNECTICUT
- Projects Inc.
- Twin Manufacturing Inc.
- Buckland Manufacturing Inc.
- Omega Engineering
- Reno Machine Company

DELAWARE
- DuPont

FLORIDA
- Air Fax
- Speed Ring
- Airport Metals

ILLINOIS
- Minority Enterprises Ltd.
- Field Tool Supply
- Simrit

INDIANA
- Howmet

IOWA
- John Deere

KENTUCKY
- Dover Corp.

MASSACHUSETTS
- Intronics Inc.
- Honeywell
- International Beam Welding
- Lee Company
- Landergren
- Valley Gage
- Poly Plating

MICHIGAN
- Kellogg Manufacturing
- Wall Colmonoy

NEW HAMPSHIRE
- Lewis & Saunders
- Gloenco-Newport

NEW JERSEY
- Valcor Engineering
- C.B. Kaupp

NEW YORK
- MacLaw Tool & Aircraft
- Steel Treaters
- Crucible Specialty Metals
- Atlas Mill Sales
- MOOG

OHIO
- Babcock & Wilcox
- Wall Colmonoy

PENNSYLVANIA
- Superior Tube
- I.N.A. Bearing

RHODE ISLAND
- Tubodyne
- Dixon

WISCONSIN
- Motor Castings
- Wrico Stamping

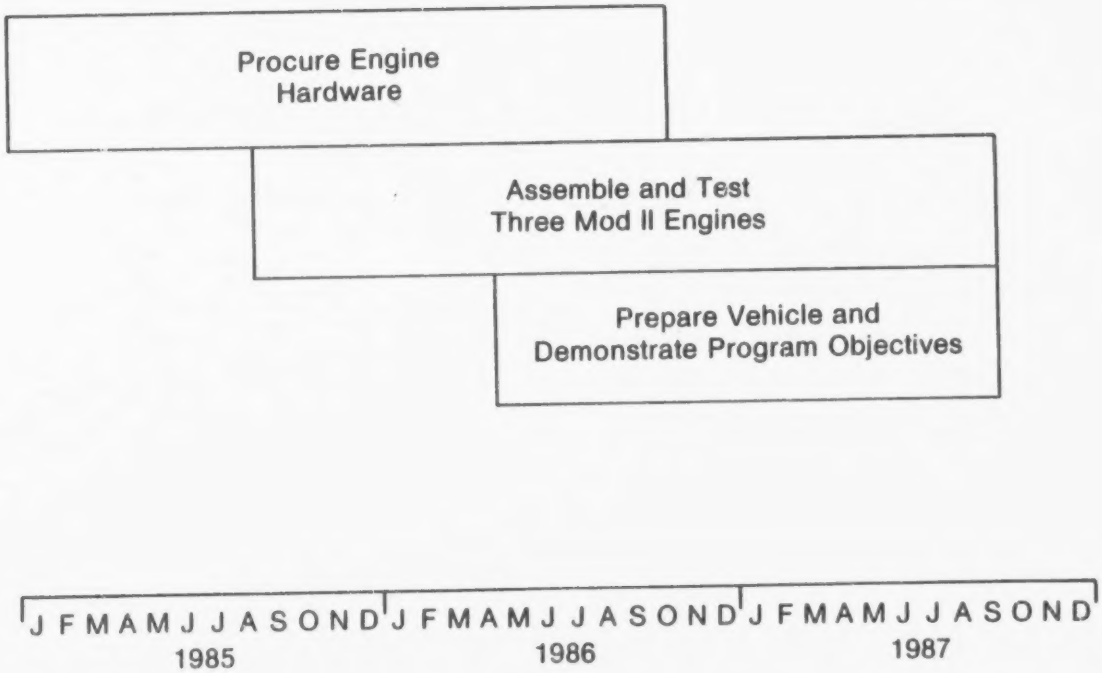

Procure Engine
Hardware
Assemble and Test
Three Mod II Engines
Prepare Vehicle and
Demonstrate Program Objectives
J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D
1985
1986
1987

Figure 1 ASE Program Schedule: Mod II Engine Development

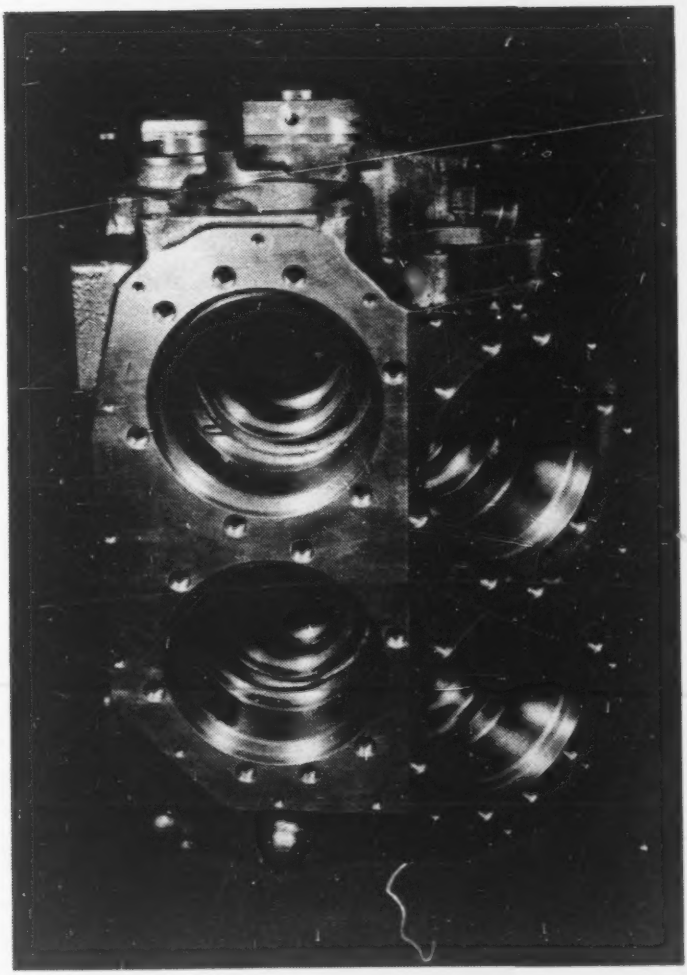


Figure 5 Single-Piece Engine Vee-Block

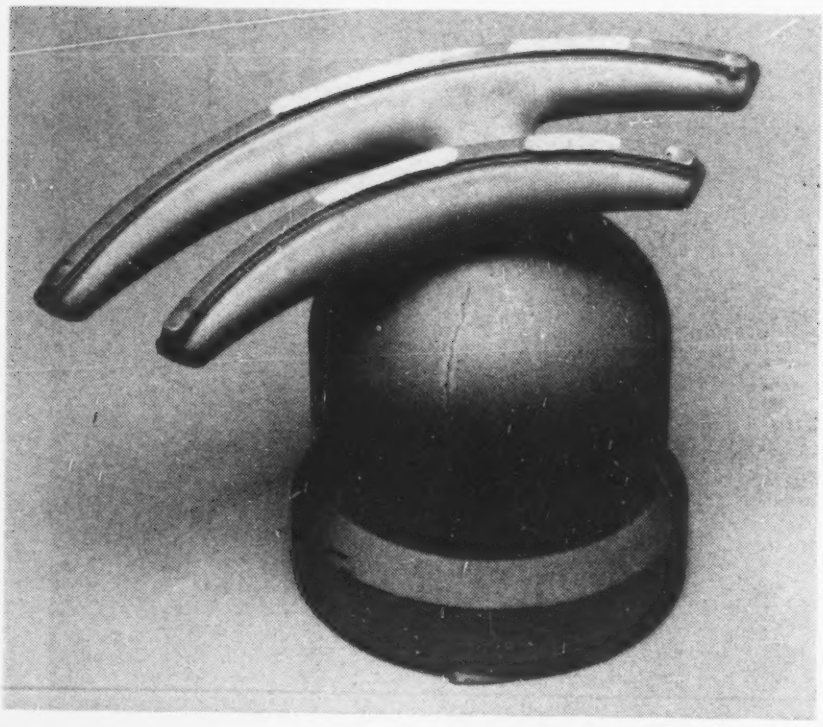


Figure 6 Annular Heater Head Casting

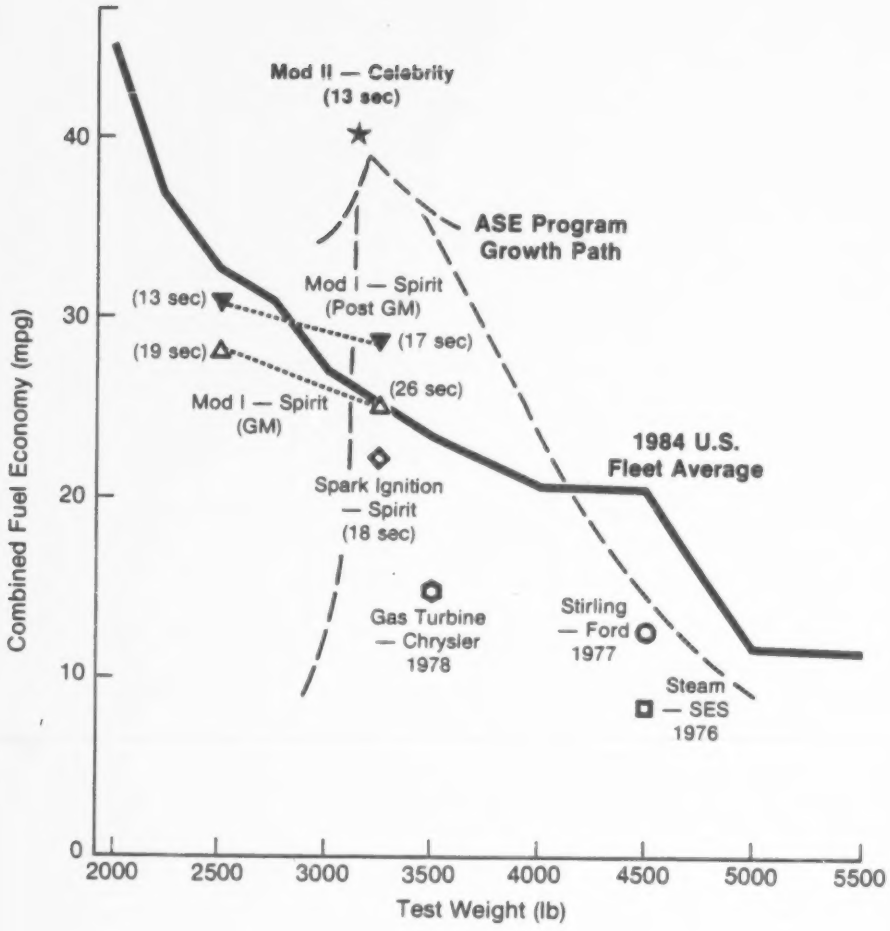


Figure 8 Stirling Engine Fuel Economy Comparison

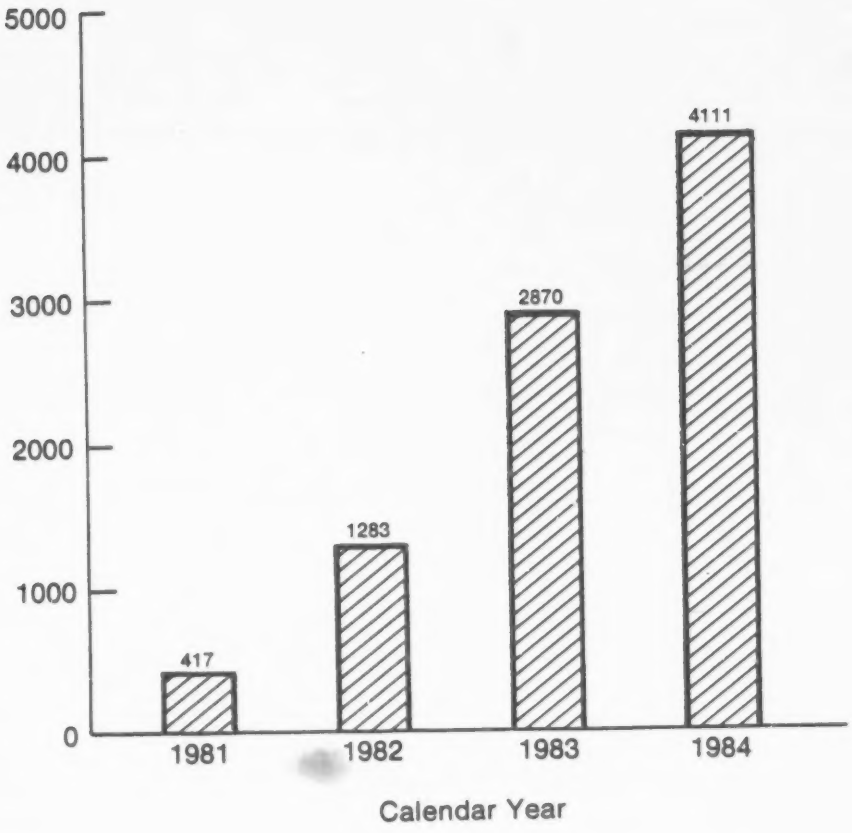


Figure 9 Mod I Engine Test Hours

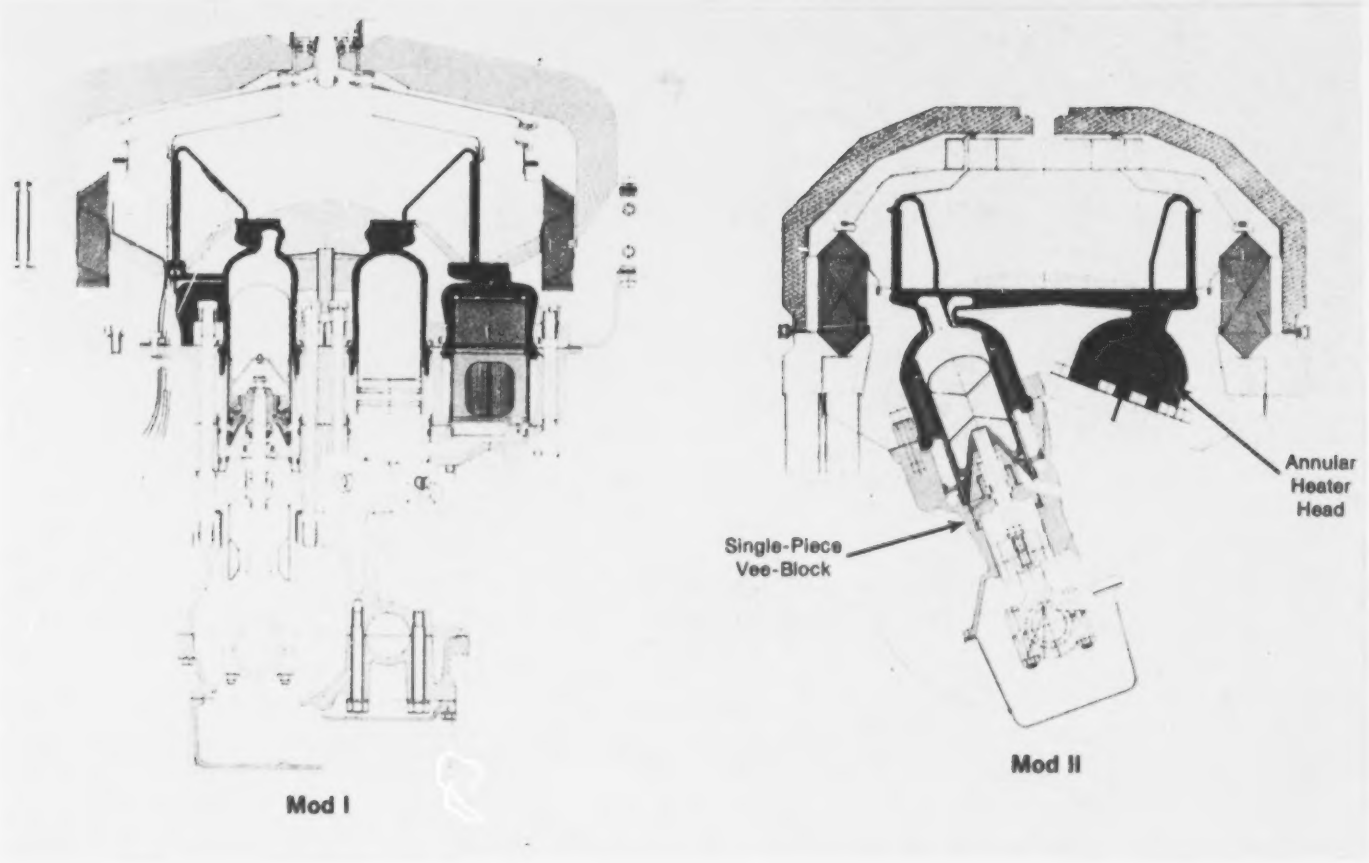


Figure 2 Comparison of Mod I and Mod II Engine Cross Sections

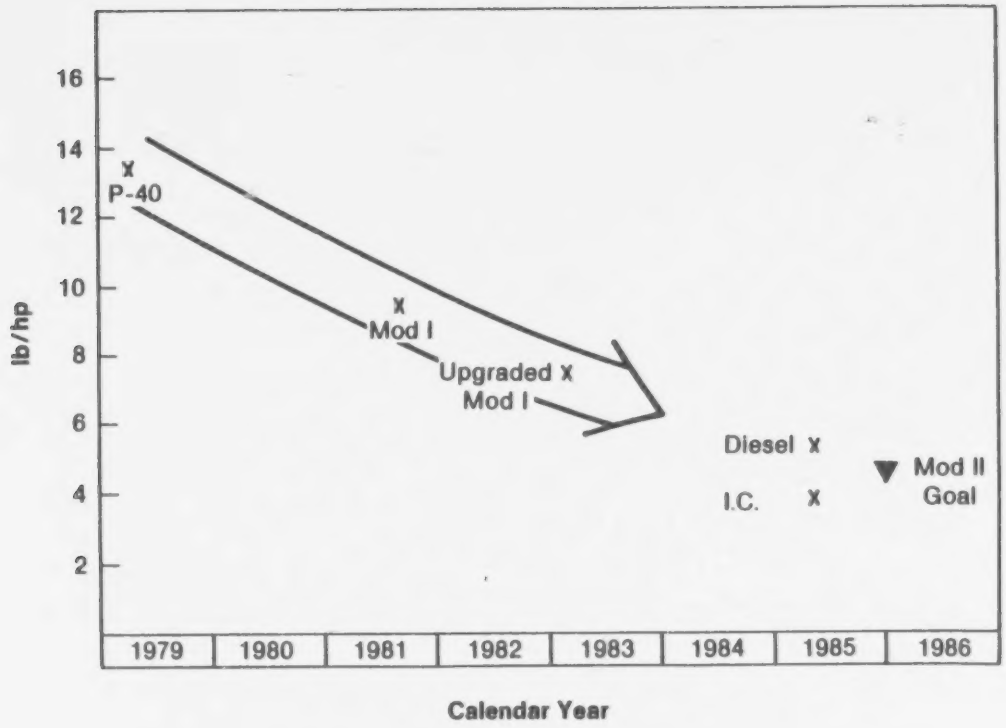


Figure 3 Reduction in Specific Weight of Mod II Engine

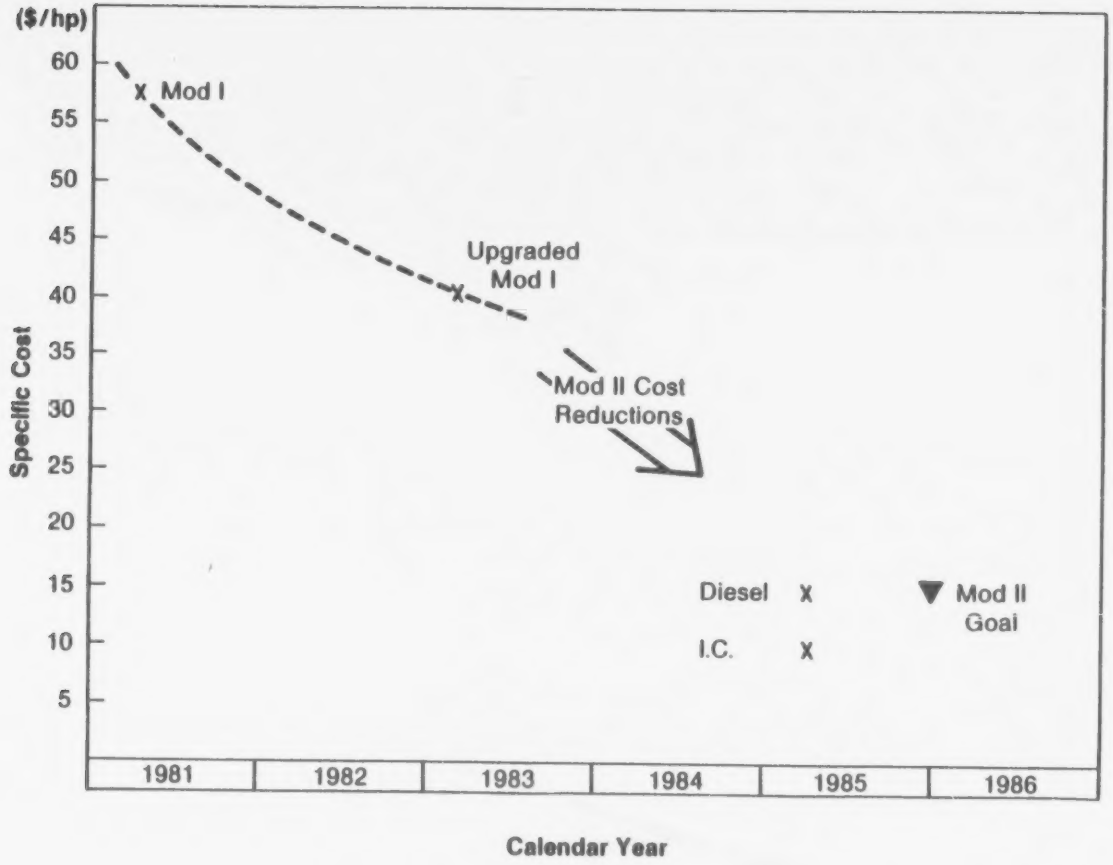


Figure 4 Cost Reduction of Mod II Engine

Figure 7 Stirling-Engine-Powered AMC Spirit

Mr. LEWIS. Our next panel will be Mr. John Boppart, vice president, engineering, Garrett Co.; Dr. Ian Macpherson, director, powertrain research, Ford Motor Co.; Mr. Harold Helms, chief project engineer for vehicle turbines, General Motors Corp.; and Mr. Ray Hudson, Eagle-Picher, Joplin, MO.

Thank you, gentlemen. The rule on the bell will be in effect so we ask you to try and hold your presentations to 10 minutes. We hopefully won't have to recess until you're finished. Mr. Boppart, why don't you start off.

STATEMENTS OF JOHN BOPPART, VICE PRESIDENT, ENGINEERING, GARRETT TURBINE ENGINE CO., THE GARRETT CORP., WASHINGTON, DC; DR. IAN MACPHERSON, DIRECTOR, POWERTRAIN RESEARCH, FORD MOTOR CO.; AND HAROLD E. HELMS, CHIEF PROJECT ENGINEER FOR VEHICLE TURBINES, ALLISON DIVISION, GENERAL MOTORS CORP., WASHINGTON, DC

Mr. BOPPART. We are assisted today by Ed Strain, who is our program manager on the AGT-101. I hope you would note that the Garrett Turbine Engine Co. is not an automotive company and did not enjoy extremely large profits last year.

The main thing that we do want to focus on today is that the ceramic technology that is being developed within the two ceramic gas turbine programs is very important to the country, and that these programs are in fact the only current sources of that development.

Why are they important? Ceramics are the only materials that will make high-temperature, low-cost gas turbines feasible which are available in this country at very low costs. The ceramics we're talking about are made with sand and air. Conversely, by being able to use these materials in high-temperature gas turbines, we greatly reduce the need for the super-alloys strategic materials which are available only from Russia and relatively unstable regions of southern Africa.

The high-temperature automotive gas turbine is feasible only using ceramics. The good side of that is when we do achieve the ability to make engines with ceramics, they will give us a very low cost that can't be achieved if even metallic materials were relatively plentiful. They enable us to get, in the small engine, the very high efficiency that yields the increases in fuel economy that are the goal of this program. It does provide a raw material that is in adequate supply to support mass production.

This is the power section of the AGT-101 which is used as the test vehicle for developing ceramics in this program (fig. 6.). Potentially all the parts that you see shaded in tan and pink which are really all the hot components in the gas turbine, are made of ceramic. This program has been extremely successful in developing these parts. When we launched the program a few years ago, it was very highly speculative that we would be able to make any of this work. I think that the progress in both ours and Mr. Helms' programs is illustrative of a very encouraging and rapid rate of evolution in this very novel technology.

The AGT Program itself is very important because it is the current focus of all meaningful ceramic technology being done in this

country. The fact that this program brings together the ceramics community, the aero-space gas turbine community, and the automotive industry means that it is providing a synergism to be the most practical and expeditious way to develop it. Again, we want to emphasize that it is very important to the ceramics being developed and tested in something that simulates a real operating environment, because our experience has been that this is the only way to do it.

This is the first program in which a ceramic gas turbine has been used as the basis from its inception and the result of this is that this program really is the vehicle by which, in the last few years, U.S. industry has stayed competitive in the very active pursuit of ceramics by European and Japanese industries.

I put this up to illustrate a few of the parts that go into this engine (fig. 13.). To date, we have made 13,000 separate parts of ceramics. We've gotten from a base level of pretty much ground zero to a reliable ability to make, in research quantities, the kind of parts we need to operate the engine. In the last year, we operated an engine that was all ceramics with the exception of the rotor for 100 hours at 2,100 degrees Fahrenheit, and we screened a lot of the components to the design temperature of 2,500 degrees Fahrenheit.

In the next year, we will be testing full ceramics engines and approaching 2,500 degrees. By the end of 1986, we have every confidence that we are going to be able to achieve the very challenging goals of the program which is demonstrating on a dynamometer the feasibility of a 2,500-degree ceramics engine.

We are not the only people that think that this is an important thing. This is a sign (fig. 9.) which appeared at the recent Japanese gas turbine conference and at this point, I would like to ask Dr. MacPherson to come forward to comment on the automotive implications.

Dr. MACPHERSON. Thank you. It is a pleasure to be here today to join in this presentation. I should like to describe some of the opportunities that we see in the long term for the ceramic gas turbine.

I have to emphasize that it is somewhat in the long term. Let's take another look at this other slide that we have here. That one shows another one of the interesting exhibits at an automotive trade show in Japan. It shows a prototype car with a ceramic gas turbine and this was the one that was referred to as possibly near term technology. We find that this is a rather startling claim to make. As Mr. Boppart said, we are not alone in looking into the potential of this device.

If we say something about what the ceramic gas turbine offers to the automotive industry, well these are the key points, providing we can attain high quality production and cost-effective volumes. We do know that this sort of engine will offer gains in fuel economy because it's a continuous combustion device and has very smooth operation; it has low noise; and we will achieve adequate, acceptable on-the-road performance. We know that we can achieve good long-term pollution control capability associated with the form of the combustion system. We know it can burn both conventional and alternative fuels. But, the automotive gas turbine is not viable without ceramics. That has been a key point of our interest

in the program. We see it as a ceramics technology development program but we do recognize, that given success of the program, the gas turbine is still a viable contender against other advanced thermodynamic systems.

I believe John wants to finish off.

Mr. BOPPART. The last point that we would like to make—really before getting to that—I want to emphasize that this program perfectly fits the definition of appropriate government involvement in the development of advanced technology which Dr. Keyworth has so well expressed. The progress has been very great. It represents real advances in very difficult new technology and the progress is continuing to be very great. We believe that there is every reason to continue to fund the AGT Program through fiscal year 1986. We, and the other contractors, have agreed to increase our cost share to a level that makes it possible to have two programs during this period. We think there's every confidence at this point that the goals will be achieved at the end of 1986. The promising result so far certainly supports the NASA/DOE interest in continuing generic programs beyond the end of this program. We believe that should be pursued vigorously because of the very large potential payoff for the country. Thank you.

Mr. LEWIS. Mr. Helms, do you want to make a statement?

Mr. HELMS. Thank you very much for the opportunity to present to you a status of our General Motors Program.

I would like to present to you just five charts to summarize the activities that we have had at GM this year.

The first chart (fig. 1) is to review again objectives that we have had in our program. Again, we point toward that 30 percent improvement over current engines—42.5 miles per gallon in a 3000 pound car as a goal for our program. I think the same as Mr. Boppart's program. Also, emissions and alternate fuels are objectives we've had and we identify two technologies—ceramics and small-scale aerodynamics—as key technologies in our program.

The next chart (fig. 2) will show you the engine that we have been testing, the AGT100, the engine on the test stand. I think, like Garrett, we have two engines that we are now performing tests with.

The next chart (fig. 3) will summarize the activities we've had in this past year. With the two engines we have accumulated in 1984 triple the amount of time we had accumulated in 1983. We have had individual builds, a single build with 66 hours on the turbo machinery, and 38 hours on a single-numbered build of an engine. We have tested the modified ceramic components like again our colleagues from Garrett we are iterating with our ceramic suppliers on the design fab evaluation parts of the program. We feel this is an essential ingredient to establish a useful technology base on these materials.

The last item there is pertaining again to the ceramics. We have engine experience with each of the ceramic components. The gassifier vanes, the combuster, and the regenerators in our engine are the high-time parts ceramics wise and we are indeed making additional ceramics components. To illustrate, we have recently obtained a Japanese-made ceramic rotor which we hope in this next year to test in our engine.

This is a picture of the ceramic rotor and we have a metal shaft joined to a ceramic rotor (fig. 4). This is one of the key fabricating or processing developments that we are trying to make and a very difficult challenge. The materials involved have significantly different coefficients of expansion and demand very unique designs and processing techniques.

On the right is the biggest of the silicon-carbide type components we make—the ceramic scroll—and again a very unique design—one that has taxed the imagination and capabilities of the ceramics industry. We think, though, that we are now seeing from two suppliers the capability to make that shape. The Norton Co. and the Carborundum Co. have both now delivered scrolls of that nature, and we have now ordered parts from a Japanese company to test their capability and to compare to our American capabilities in ceramics.

The last chart shows a schedule that we derived in cooperation with NASA/DOE this year to finish this program (fig. 5). Again, like Mr. Boppart, we hope that by the end of 1986 to have met initial performance and endurance goals for the engine and the ceramic components and the small scale aerodynamic challenges that we have both faced.

Mr. Chairman, that concludes my presentation. I would be pleased to answer any questions you might have on the AGT100 program.

Mr. LEWIS. Thank you gentlemen. I would like to hear from all three of you if possible. To what extent does the AGT program benefit from research being conducted by NASA on small engine technology? Now you recommended its continuance. I would like to know what other great benefits that you see from their research.

Mr. BOPPART. I think there is a very intimate connection between the aerodynamic technology which NASA has supported over the years and which I am happy to see that NASA is becoming more active in supporting in small engines and the kind of component performance that is essential to practicality in a gas turbine of this size. These engines require the achievement of high levels of component performance in very small physical sizes. The work that has been and is supported out of NASA/Lewis is certainly very integral to that.

Mr. HELMS. I would agree with John that the technologies coming out of this program will be very applicable to some of the goals and objectives set forth in the NASA Small Engine Technology Program. We are hopeful that the materials technology will translate as well as the aerodynamics technology.

The engines to be involved in the NASA Small Engine Technology Program are yet to be defined and I think the engines chosen and the cycles chosen may impact the degree of transferability of the technology coming out of the agency projects. There is a definite synergism between the two.

Mr. BOPPART. Perhaps there is a matter of perspective that I should point out. The NASA Small Engine Component Technology Program is currently under procurement What is called small engines actually represents engines that are about 10 times the true flow of these engines.

Mr. HELMS. This one flows three-quarters of a pound per second max flow and the NASA engines that we've discussed so far are 5 to 10 pounds per second in range. It is a different scale factor and, in fact, the AGT engine is a much more difficult problem statement.

Dr. MACPHERSON. I don't really want to comment on the NASA small engine, but I would like to comment on the relationship between the materials work in this program and comparable work in reciprocating engines. From the Ford Motor Co. point of view, we do see real benefit in thinking not only of the rotating engines, but the diesel engine as well.

Mr. LEWIS. Go ahead and comment at this point if you'd like.

Dr. MACPHERSON. We are very pleased to see that DOE is beginning to pick up the subject of the adiabatic diesel. We have a fair amount of our own work going on in-house which is very much involved in ceramics. In our own work both on the AGT101 and in our diesel work, we deal very closely with the ceramics technology field.

Mr. LEWIS. I noticed that you showed a Japanese automobile running on a ceramic engine. To what degree do you think they are ahead of us? Do they have something ready to be operational, or close to it?

Mr. BOPPART. I think in level of technology that we are still probably a little bit ahead. The area that has to be of concern to all of us is the level of effort that's going on in the area of ceramics and ceramics applied both to reciprocating and gas turbine engines in Japan is on order of magnitude larger than it is in this country. There are very large numbers of people involved in them. All of the major companies at all related to this area have very active programs and they are very well coordinated by the Government. I think the challenge before us is to maintain enough effort and momentum not to be simply swamped by the very large magnitude of the Japanese effort.

Mr. LEWIS. What cost share are you contributing to the project for 1985 and 1986?

Mr. BOPPART. Through the current period, we have matched every dollar of Government investment with 55 cents of our own money. In 1986 because of the funding crunch and in order to make it possible for dual programs to continue as desired by HASA/DOE and ourselves, we have increased our cost share and we have essentially tripled the amount of our cost share for next year.

Mr. HELMS. We have more than doubled our cost share this past year. Like the Garrett Co. General Motors has had a significant ceramics activity. Related activities have contributed far more than the Government relative to some of these items. Alternate fuels has been one of our objectives. General Motors has demonstrated in a separate turbine program the use of coal and our expenditure has been on the order of $10 million. We've demonstrated that this kind of turbine can use coal as a fuel. We have such a turbine now operational at the General Motors Technical Center. We are about to demonstrate methanol fuel and we believe that the methanol fuel is already an available alternate fuel for the automotive industry.

We have worked ceramic and diesel engines as Ford has done. Our cost share we think is very significant. Direct cost share and indirect cost share are the subjects that have been laid on the table. I think most of your share has been indirect as has ours. Direct cost share is far less obviously.

Mr. LEWIS. Dr. Macpherson?

Dr. MACPHERSON. I really can't add much more to what my colleague has said. We have increased our formal cost share that appears in the financial returns. Equally we find a very close feedacross from our other ceramics activities. The use of equipment and facilities is all-aiding in this program.

Mr. LEWIS. What spinoffs do you gentlemen see at this point as a result of the work to date on the ceramics in your engine programs?

Dr. MACPHERSON. As I have stressed before, we have in the last 2 years much increased our own internal efforts on diesel engines. We found that we can read into those engines similar technology for materials that we've evolved for the gas turbine. We're finding the silicon nitrides, the silicon carbides are of direct interest and application in those engines.

Mr. LEWIS. When do you feel that the Federal Government's role ceases and you take over responsibility for in-house research?

Mr. BOPPART. I think that the present program is properly scoped in that regard. The point at which we hope to arrive at the end of fiscal year 1986 is one in which the feasibility of the technology has been demonstrated to an extent that it will be practical for an automotive or other company—I would like to comment that there are currently active spinoffs into the solar power generation and light aviation power plant areas from this specific program. I think the fundamental technology will have been demonstrated and a sufficient base will exist for the start of industrialization. I think it's very important that the base that has been established in ceramics continues to be supported by further Government supported research and technology in ceramics past that point.

Mr. LEWIS. Mr. Helms, I don't want to short-change you. I thought Dr. Macpherson was going to answer the question for all three. Go ahead and tell us about spinoffs.

Mr. HELMS. There are several spinoffs. We have developed a new set of design methodology as we have addressed the brittle materials problem statement. This is a statistical approach to design as opposed to earlier approaches which were far less rigorous. We're finding the design methodology to be useful as we address aircraft engines, as we address gasoline engines and diesel engines. Further, we're finding in the fabrication and processing of ceramics that new processing techniques are required. We feel that will spinoff and benefit us as we address ceramic requirements in current automobiles like oxygen sensors, etera.

No doubt, the spinoffs from processing and fabrication are very important to us. As far as application is concerned, we also at GM are working the problem statement of applying ceramics to gasoline and diesel engines as well as to turbine engines. My personal assessment in the state-of-the-art is that we have perhaps an approaching technology base that may be adequate for the application of ceramics to stationary components. I believe as we address

the dynamic components, the piston in the ice and diesel engines, the rotor in the gas turbine, we have identified a lack of reliability, a lack of knowledge relative to defect identification which I think makes our technology base incomplete for the most demanding ceramic components. My frank opinion is that when we reach the end of 1986 that we still will have a deficiency relative to reliability of these components and it will be necessary to do additional technology development activity and I suggest government support there would be required.

I believe the program to which Mr. Boppart alluded on his chart was probably also recognizing this reliability and toughness problem that I believe both companies have identified with these ceramic materials. I see additional work required when we've completed the current program.

Mr. LEWIS. I would like for you to respond to how much Government support in these specific programs that you would require at a minimum level. This is the same type of question that I asked the Stirling people; if you had a percentage how would that affect the program as you go down the pike from what is requested now in the budget? How is it going to affect you? Are you prepared to increase the allocation from your companies if that would happen?

Mr. HELMS. This past year we more than doubled our cost share on the AGT100 Program. We had hoped that would carry us through the 19G6 time frame. As we look beyond 1986 and we would look at additional programs, I think we would seriously consider increased cost share as we look down the road. Again, it has to be a function of the status of our overall company and profitability of our company at the time that determination would be made. We feel that the ceramics technology has progressed magnificently because of the support of these programs. Because of that progress, we would consider a larger cost share than we have now.

Mr. BOPPART. If your question related to what if the funds for 1986 were reduced significantly, I think from our point of view both of our programs have been squeezed about as hard as they can be in order to achieve the goals at the end of 86 in a dual program. I believe that if significantly reduced funding were made available that the only practical thing would be to give up the benefits of having two competitive programs.

Mr. LEWIS. What problems do you forsee in reaching the 30 percent fuel efficiency improvement goal established for 1986?

Mr. HELMS. I see two problems. One is that I don't think we will have satisfied all of the aerodynamic requirements and that because we have cutback significantly on our programs already. I doubt that we will have met all of our ceramic materials requirements. I think it's highly questionable that we will meet the 30 percent improvement in fuel economy by the end of 1986. I believe that, relative to the ceramics, it's the identification of reliability and toughness problems that will prevent us from meeting the endurance activities. I doubt if we will have solved enough of the heat loss and/or leakage problems relating to aerodynamics to successfully meet the 30 percent improvement in fuel economy relative to gasoline or diesel engines.

Mr. BOPPART. I am more optimistic than Gene is. The goal that has been established for this program is a difficult one and

wouldn't be worth the Governments money if it were not a challenging and substantial leap ahead in technology. However, the progress that has been made so far is very encouraging and I really see no reason at this point why if we continue to have this kind of success we cannot achieve the goals of the program at the end of 1986.

Mr. LEWIS. Mr. Boppart, I would like to ask you—Mr. Helms alluded to stationary parts—do you feel also that you have problems also with the rotating parts?

Mr. BOPPART. It's been recognized since the beginning of the program that the rotating component is the most difficult part of it. The progress has been made much more rapidly with the static parts. I feel that we are now in a period in which we are beginning to see the same kind of rapid progress in the rotor itself. I am very optimistic that within the next month or so we are going to be operating a rotor at essentially full conditions in our engine. I think that Gene's points are very well taken with regard to how reliably the fabrication techniques will be developed for the rotor by the end of the program. I do not think there is any fundamental obstacle to achieving the original goals.

Mr. LEWIS. I would like to ask this question of all three—if it would affect the security of your operation, just say so and I'll accept it. Are you trying a full cast with the ceramic rotating parts such as the rotor and the shaft and using sleeve or something like that on the exterior?

Mr. BOPPART. Both of our engines use a form of joint between a metallic shaft and the ceramic rotor. In the case of our engine, we use a sleeve bearing—it's actually a gas lubricated sleeve bearing—associated with the rotor. In the Allison engine they use antifriction ball bearings. This is one of the reasons why all the agencies involved have been very enthusiastic about maintaining a dual program. There are different approaches being explored and multiple opportunities for success by doing that.

Mr. HELMS. If you had an integral ceramic shaft with a rotor for example, we would find in our case that the heat conducted to the bearings would not be livable at the full operating conditions. We make a transition to the metal shaft and we do that through a heat dam material which prevents the heat flow from the rotor into the bearing cavity. We must have that kind of construction.

Mr. LEWIS. I have no more questions. Thank you for your attendance today and for your testimony.

[The prepared statements of Mr. Boppart and Mr. Helms follow:]

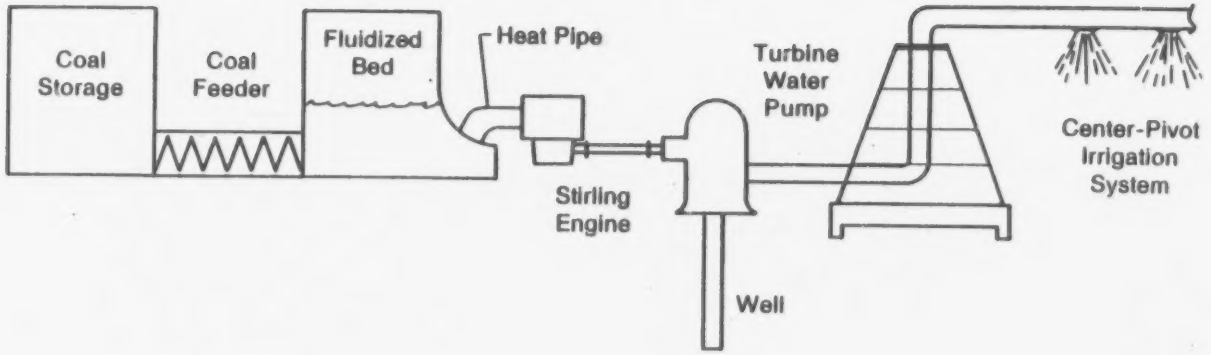


Figure 10 Coal-Fired Stirling Engine Irrigation System

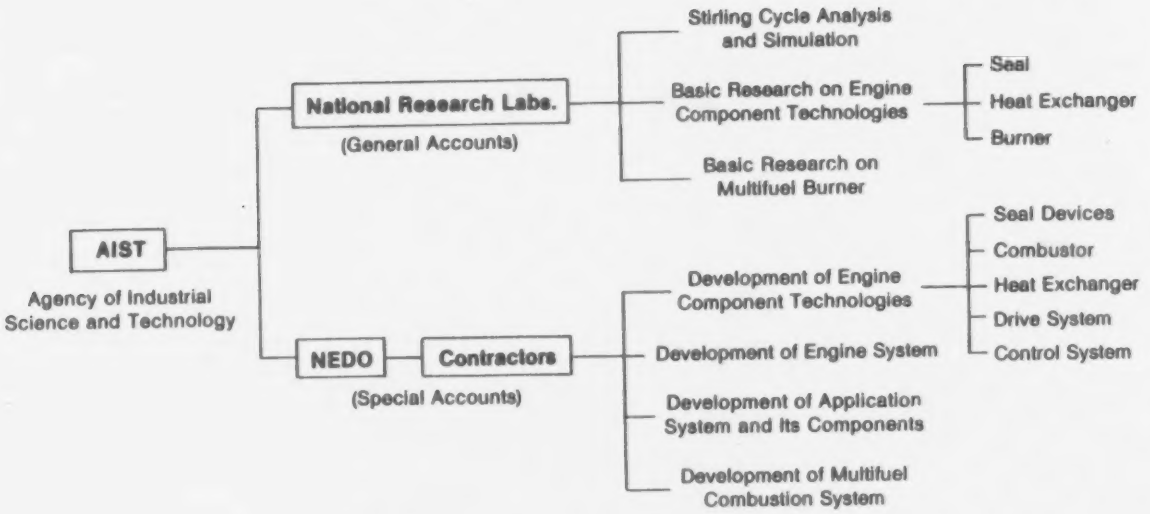
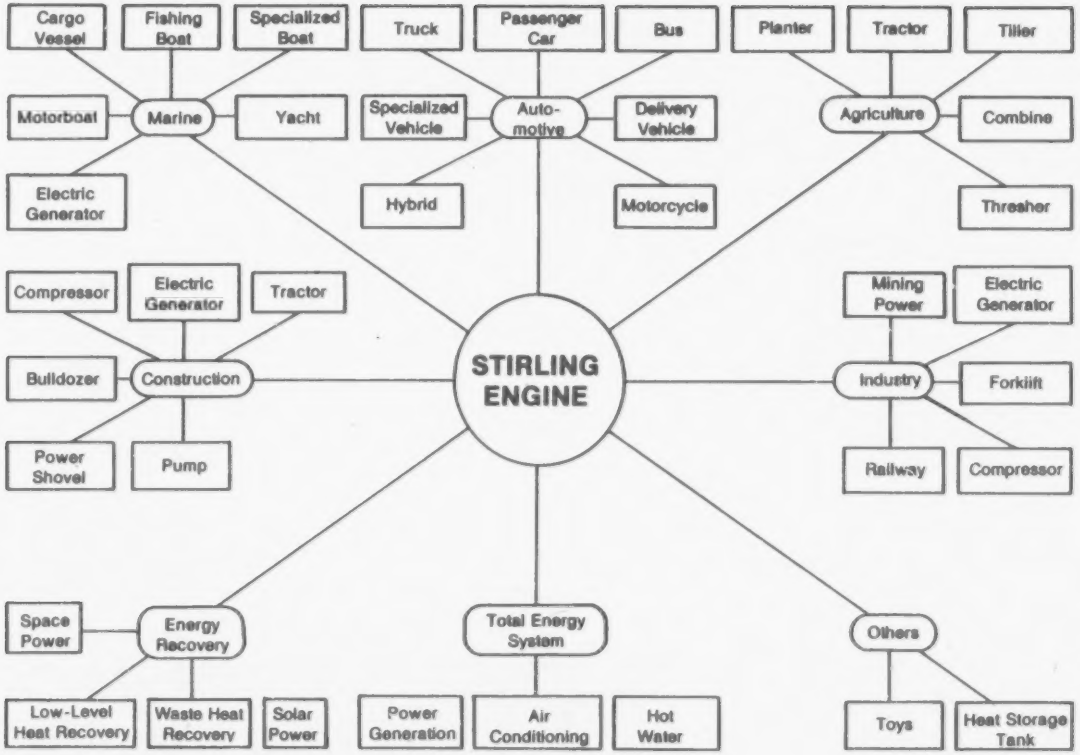


Figure 11 Japan's AIST Project Organization and R&D Approach



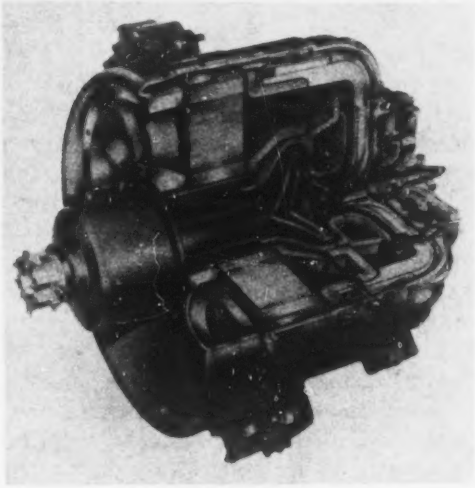
*Source: Japanese New Energy Development Organization (NEDO) Brochure, 1984

Figure 12 Japanese Stirling Engine Applications

TESTIMONY BEFORE
THE SUBCOMMITTEE ON TRANSPORTATION,
AVIATION AND MATERIALS
OF THE
COMMITTEE ON SCIENCE AND TECHNOLOGY
U.S. HOUSE OF REPRESENTATIVES

PROGRESS REPORT
GARRETT/FORD
AUTOMOTIVE
GAS TURBINE PROJECT

AGT101



27 FEBRUARY 1985

JOHN BOPPART
VICE PRESIDENT, ENGINEERING
GARRETT TURBINE ENGINE COMPANY

DR. IAN MACPHERSON
DIRECTOR, POWERTRAIN RESEARCH
FORD MOTOR COMPANY

GARRETT TURBINE ENGINE COMPANY
A DIVISION OF THE GARRETT CORPORATION
PHOENIX, ARIZONA

JOHN BOPPART

VICE PRESIDENT, ENGINEERING

Education

B.S. in Mechanical Engineering, California Institute of Technology, 1952

M.S. in Mechanical Engineering, California Institute of Technology, 1953

Work History

1957 to Date: Garrett Turbine Engine Company

- Vice President, Engineering
- Director of Engineering
- Assistant Director of Engineering, Power Systems
- Assistant Director of Engineering, Pneumatic Systems
- Chief of Pneumatic Control Systems
- Senior Project Engineer, Pneumatic Actuation Systems
- Project Engineer, Pneumatic Control Systems
- Assistant Project Engineer, Advanced Power Generation Systems
- Senior Systems Engineer, Systems Support Group

1953 to 1957: AiResearch Manufacturing Company of Los Angeles

- Preliminary Design Engineer
- On loan to Advanced Design Group, ANP Project, Oak Ridge National Laboratory (1956)

Responsibility/Experience

Mr. Boppart currently is responsible for all engineering activities for Garrett Turbine Engine Company.

As Assistant Director of Engineering, Mr. Boppart was responsible for all engineering activities associated with all AiResearch Power Systems products. Prior to this, he was similarly responsible for all AiResearch Pneumatic Systems products.

All engineering functions involving the Power Systems and Pneumatic Systems product lines were under his direction including engineering estimates through design, development, and qualification, and the production liaison activities during the follow-on production deliveries.

Mr. Boppart's prior experience also includes work in various capacities of engineering on pneumatic valves and controls, air motor pneumatic actuation systems, missile and space control valves, space power systems, gas turbine auxiliary power systems, and aerospace environmental control systems.

IAN MACPHERSON

Director — Powertrain Research Laboratory
Ford Motor Company

Education

B.S. in Physics — University of Manchester, England, 1951

M.S. — Cosmic Ray Physics

PhD. — University of Manchester, England, 1952/1955

Work History

1971 to Date: Ford Motor Company

- Director, Powertrain Research Laboratory
- Chief Engine Engineer, Truck Operations, Ford of Europe
- Executive Engineer, Truck Operations, Ford of Europe

1955 to 1971: Rolls Royce Ltd., Aero-Division, England

- Assistant Chief Research Engineer, Combustion and Turbine Systems
- Head of Advanced Research Laboratory
- Section Head, Gas Dynamics Research
- Project Engineer, Submarine Nuclear Reactor Project
- Project Engineer, Combustion Research

Responsibility/Experience

Dr. Macpherson is responsible for all activities within the Powertrain Research Laboratory of the Ford Motor Company, with particular emphasis on future engines and transmissions of relevance to automotive and tractor systems, including alternative fuels.

As Chief Engine Engineer, Truck Operations, Ford of Europe, he was responsible for diesel engine design and development for commercial vehicles. This covered advanced engineering, development of new products and close liaison with production and field activities, including industrial engines.

Work at Rolls Royce covered a span of technologies, ranging from nuclear reactors for submarine propulsion; gas dynamics and combustion at hypersonic conditions; materials and basic physics research; to line responsibility for the combustion and turbine technology embodied in all Rolls Royce gas turbines.

GARRETT TURBINE ENGINE COMPANY
A DIVISION OF THE GARRETT CORPORATION
PHOENIX, ARIZONA

Mr. Chairman and members of the subcommittee:

My name is John Boppart (Figure 1). I am Vice President of Engineering for Garrett Turbine Engine Company, a division of the Garrett Corporation (a Signal Company). I would like to introduce Dr. Ian Macpherson, Director, Powertrain Research of Ford Motor Company. Dr. Macpherson will join me today in presenting this testimony.

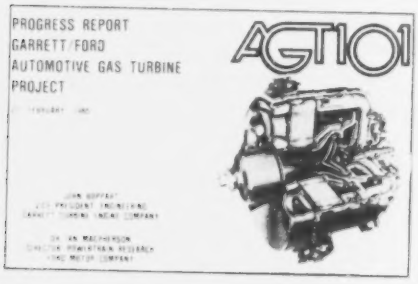


Figure 1. Testimony Before the Subcommittee on Transportation, Aviation, and Materials

Garrett and Ford Motor Company are working together on the Advanced Gas Turbine (AGT101) Program under contract to the Department of Energy and NASA (Figure 2). Garrett is the prime contractor, with major support from Ford. Other major subcontractors supporting us in this program are Carborundum Company, Corning Glass Company, and Airesearch Casting Company (another division of Garrett).

The AGT101 team is developing high-risk long-range technology for advanced automotive gas turbines for future automotive and other power plant uses. Major emphasis of the program is to develop ceramic component technology for gas turbine engines.

In today's testimony, I wish to focus on why this country needs the ceramics technology that is being provided only by the AGT program (Figure 3).

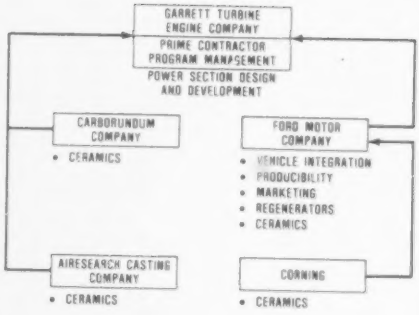


Figure 2. Garrett/Ford AGT101 Program Team

U.S. NEEDS CERAMICS TECHNOLOGY THAT IS ONLY BEING PROVIDED BY THE AGT PROGRAM

Figure 3. Today's Focus

I. What Is Ceramics?

- Ceramics is a science related to non-metallic and inorganic materials.
- Silicon, nitrogen, and carbon are elemental constituents (i.e., sand).

II. Why Is Ceramics Important?

- Elemental constituents are readily available in the U.S. in an inexhaustible supply.
- The need for strategic materials[1] is reduced (many heat engines, including gas turbines, employ strategic materials).
  - Dependence on unreliable foreign sources[2] is reduced, providing protection of National Security.

[1] "*A strategic material is one for which the quantity required for essential civilian and military uses exceeds the reasonably secure domestic and foreign supplies, and for which acceptable substitutes are not available within a reasonable period of time.*" *Office of Technology Assessment,* Strategic Materials: Technology to Reduce U.S. Import Vulnerability *(January 1985), p. 13.*

[2] "*Three nations, South Africa, Zaire, and the U.S.S.R., account for over half of the world's production of chromium, cobalt, manganese, and platinum group metals.*" *Ibid., p. 7.*

- There are not enough strategic materials in the world for automotive gas turbine production.
- Cost of strategic materials for an automotive gas turbine is prohibitive.

- Ceramics[3] offers the automotive gas turbine:
  - Capability to operate at higher temperatures without cooling, thus providing higher efficiency
  - Better fuel economy
  - Substantially lower cost potential
  - Adequate raw material for mass production
  - Lower friction (tribology)
  - Lower weight
  - Lower inertia of rotating parts (less energy) (Figure 4).

- MATERIALS AVAILABLE IN U.S. IN INEXHAUSTIBLE SUPPLY
- NEED FOR STRATEGIC MATERIALS REDUCED
- CERAMICS FOR AUTOMOTIVE GAS TURBINE ARE ESSENTIAL
  - COST
  - HIGHER EFFICIENCY — BETTER FUEL CONSUMPTION
  - ADEQUATE RAW MATERIAL FOR MASS PRODUCTION

Figure 4. The Importance of Ceramics

III. Where Are We In Ceramics Technology Development?

- The AGT101 program has processed over 13,000 first-generation ceramic parts for evaluation.
- Limited component and engine testing has been conducted under actual operating environment conditions.
- Ceramics is at the stage of development that metallurgy was 30 years ago (Figure 5).

IV. Why Is The AGT Program Important?

- The AGT program is the major U.S. Government/industry-sponsored program devoted to focusing ceramics from the research laboratories to a practical application — an automotive gas turbine engine.

- AGT101 HAS PROCESSED OVER 13,000 FIRST GENERATION CERAMIC PARTS
- LIMITED TESTING UNDER ACTUAL OPERATING ENVIRONMENT
- CERAMICS ARE 30 YEARS BEHIND METALS DEVELOPMENT

Figure 5. Ceramics Technology Development Status

- The program is the only U.S. program that has allowed an all ceramic engine hot section to be designed from inception (Figure 6).

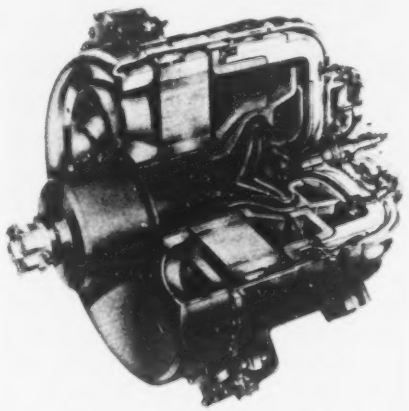


Figure 6. AGT101 Power Section

[3] *"Ceramics, composites, and unconventional metallic materials have properties that suggest they might serve as substitutes for conventional materials that require strategic metals." Ibid., p. 52.*

- The program has allowed ceramics expertise from the auto industry, the gas turbine industry, the ceramics industry, and the government to be combined to develop ceramics technology and integrate this technology into the gas turbine operating environment via test rigs and engine test beds — the only practical approach to ceramics technology development.
- The program has allowed the team to advance this long-range, high-risk technology, which no individual company could afford.
- The program has allowed the time and resources for an iterative give-and-take ceramics design and development effort.
- The program has allowed the fabrication of test rigs and engine test beds for extensive ceramics development and evaluation.
- Without the AGT program, ceramics development would take much longer and cost much more.
- The program has allowed the U.S. industry to stay competitive with, and perhaps ahead of, foreign ceramics technology development of high technology materials.
- The AGT101 gas turbine operates without oil in the hot section — an air bearing is utilized — thereby offering less friction (tribology) and lower energy consumption to the future automotive driving public (Figure 7).

- FOCUS OF CERAMICS TECHNOLOGY DEVELOPMENT IN U.S.
- CERAMICS BEING DEVELOPED BY INDUSTRY AND GOVERNMENT EXPERTISE IN THE MOST EXPEDITIOUS AND PRACTICAL WAY
- CERAMICS TESTED AND EVALUATED IN ACTUAL OPERATING ENVIRONMENT
- ONLY PROGRAM THAT HAS ALLOWED CERAMIC DESIGN GAS TURBINE FROM INCEPTION
- HAS ALLOWED U.S. INDUSTRY TO STAY COMPETITIVE WITH FOREIGN CERAMICS TECHNOLOGY DEVELOPMENT

Figure 7. The Importance of the AGT Program

V. What Does The Ceramic Gas Turbine Offer The Auto Industry?

- The auto industry must have available high quality products in cost-effective quantities to meet customer requirements. Providing the technology embodied in the AGT101 can be developed to meet these demands, the automotive gas turbine would provide several attractive features, as below.
- Small-car fuel consumption in full-size cars and light trucks.
- The lightweight rotary power unit uses continuous combustion. This combination ensures smooth operation and low noise. Vehicle acceleration and top speed are more than adequate when advanced transmissions are used.
- The continuous combustion process has the additional benefit that it can be developed for excellent long-term pollution control.
- The multi-fuel capability of the gas turbine ensures that it is not solely dependent on petroleum-based fuels. Alternative fuels derived from non-petroleum sources can be burned efficiently and cleanly in the engine. This particular feature is highly relevant to the longer term, when the present availability of conventional fuel, both domestic and imported, could be constrained for many reasons.
- A number of engine concepts using advanced thermodynamics (adiabatic diesels, turbocompound engines, bottoming cycles) is under investigation in the quest for ultimate fuel economy. The automotive gas turbine is a viable contender in this continuing research endeavor around the world.
- The United States auto industry is facing persistent competition from overseas. Our competitors are well aware of the potential of the gas turbine, in particular its ceramics technology. Active joint industry, university, and government programs are underway in Japan, the United Kingdom, and Germany. A display at the International Gas Turbine Conference in 1984 in Japan showed a Japanese prototype vehicle, with the caption "Ceramic Gas Turbine Engine — a powerplant of the near future," a significant statement for technology we still consider long range and high risk (Figures 8 and 9).
- However, the automotive gas turbine is not practical without the ceramics technology under development in the AGT program (Figure 10).

VI. Are Other Government Agencies And Industry Interested?

- The military services have all expressed interest in

- JAPANESE PROTOTYPE CAR
  - REAR MOUNTED DUAL-AXIS 100 HP CERAMIC GAS TURBINE
    - OPERATING TEMPERATURE = 2462F
    - CERAMIC COMPONENTS
      - TURBINE BLADES
      - TURBINE SHROUD
      - COMBUSTION CHAMBER LINES
      - HEAT EXCHANGER CORE

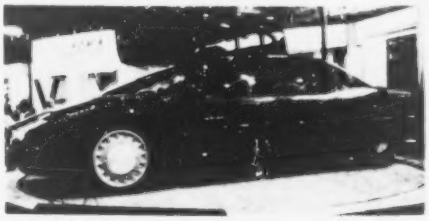


Figure 8. Foreign Ceramics Competition is Developing

Figure 9. Japanese Gas Turbine Engine

- AGT TECHNOLOGY, COUPLED WITH HIGH QUALITY PRODUCTION IN COST EFFECTIVE VOLUMES, COULD PROVIDE:
  - SMALL CAR FUEL CONSUMPTION IN FULL SIZE CARS AND LIGHT TRUCKS
  - SMOOTH OPERATION, LOW NOISE, AND GOOD "ON-THE-ROAD" PERFORMANCE
  - LONG-TERM POLLUTION CONTROL CAPABILITY
  - ABILITY TO BURN CONVENTIONAL AND ALTERNATIVE (NON-PETROLEUM) FUELS
- FOREIGN COMPETITION IS PURSUING CERAMICS TECHNOLOGY
- THE AUTOMOTIVE GAS TURBINE IS NOT VIABLE WITHOUT CERAMICS

Figure 10. The Auto Industry Needs Ceramics Technology

ceramic gas turbines. The AGT program serves as the focus for government interest in ceramics. The services wish to take advantage of the work sponsored by the AGT program.

- The aircraft industry is interested in gas turbines that are more efficient, lighter weight, and less expensive. The use of ceramics offers these potential gains.
- The AGT101 is a strong candidate for a solar generator set currently being considered for long-range development by the DOE.
- A ceramic AGT101 derivative has been studied by NASA for aircraft propulsion application.
- Industrial gas turbine applications are candidates for ceramics.
- Industry is evaluating ceramic turbocharger turbine wheels for automotive application.
- Ceramic components are beginning to be employed by industry for a wide range of production applications (Figure 11).

VII. Where Are We Going In FY85-86?

- The AGT teams have increased their cost share in FY85 and 86 to allow both teams to continue to program completion (Figure 12).
- Ceramic parts have been, and are continuing to be, tested under simulated engine operating conditions, individually and then as subassemblies, to qualify them for engine test evaulation. A limited number (400+) of the parts has passed these screening tests, but many more must pass.
- Ceramic component rig testing to 2500F has been initiated. (The AGT101 operates at 2500F to obtain

- AGT PROGRAM SERVES AS FOCUS FOR GOVERNMENT INTERESTED IN CERAMICS
- OTHER APPLICATIONS
  - CERAMIC GAS TURBINES FOR AIRCRAFT, SOLAR GENERATOR SETS, INDUSTRIAL ENGINES
  - TURBOCHARGER TURBINE WHEELS
  - WIDE RANGE OF CERAMIC PRODUCTS BEING INTRODUCED INTO PRODUCTION

Figure 11. Interest of Government Agencies and Industry Served by AGT Program

optimum fuel economy.) Much more test experience at these high temperatures is required to resolve problems and guide materials development before successful engine test bed operation can be assured.

- Ceramic subassemblies have been tested in the engine test bed for over 100 hours at 2100F. This was accomplished in 1984 and is considered the most significant milestone to date. Ceramic components and subassemblies that successfully pass the 2500F rig testing will be qualified for initiation of the 2500F all-ceramic engine test program, scheduled to start in 1985.
- The gas bearing (which operates without oil) in the hot section of the engine was developed to a high level of performance in 1984 and is ready for the 2500F engine test bed operation.
- The ceramic turbine rotor development was considered the most challenging job when the AGT101 program was initiated. It has taken five years to develop the turbine wheel to the point at which it can be successfully cold spin tested to 115,000 rpm as a proof test. Rotors also have been hot tested in a rig and in an engine test bed to 1600F.
- Ceramic turbine rotors will continue to be developed for testing in the engine test beds, first at 2100F and later to 2500F. These tests are planned for 1985.
- The ceramic parts, subassemblies, and rotors must pass the rig-simulated engine environment tests before they are tested together in the engine test beds. By the end of 1986, the all-ceramic engine will be tested on an engine dynamometer for:

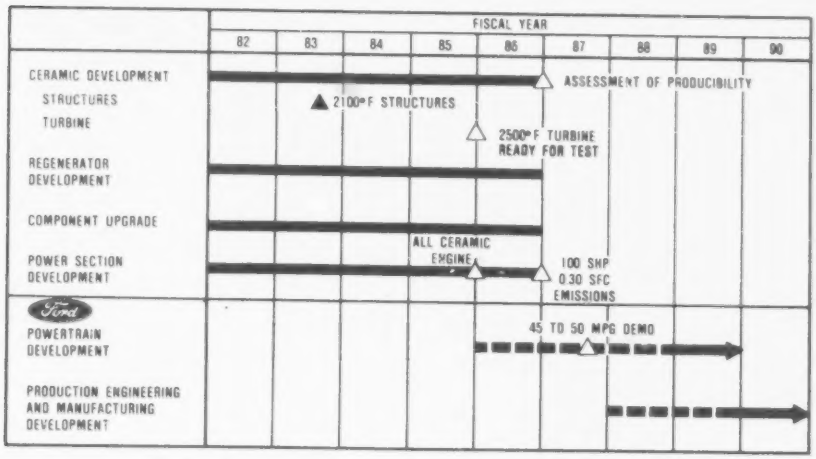


Figure 12. Restructured AGT101 Program Schedule

- Fuel Economy Demonstration
- Power Level Assessment
- Emissions Measurement

- The proof-of-concept of the ceramic gas turbine will have been verified (Figures 13 and 14).

VIII. Where Do We Go In The Future?

- Both NASA and the DOE have initiated generic ceramics programs. These programs are coordinated to assure complimentary efforts to foster the next generation of ceramics in the United States. Universities, industry, and the Government will evolve new, tougher, more reliable, and easier-to-produce ceramics or derivatives.
- The AGT101 is expected to be successful in demonstrating proof of concept using high technology materials still in the laboratory phase. We know that questions relating to second-generation materials, supply infrastructure, the demands for high quality components produced in cost effective quantities, and others will remain unanswered.

- FIRST CERAMIC ENGINE TESTED FOR 100 HOURS AT 2100F IN 1984
- CERAMIC PARTS MOVING FROM INDIVIDUAL AND SUBASSEMBLY SIMULATED OPERATING TESTING TO ACTUAL ENGINE TEST BED OPERATION - 2500F
- ALL CERAMIC ENGINE TO BE TEST EVALUATED IN FY86 TO VERIFY PROOF-OF-CONCEPT CERAMIC GAS TURBINE
  - FUEL ECONOMY
  - POWER LEVEL
  - EMISSIONS
  - CERAMIC PARTS MANUFACTURING VIABILITY

Figure 14. AGT101 Development Direction for FY85-86

- The value of using realistic operating hardware when attempting to answer these questions is beyond doubt. These programs offer already-paid-for test rigs and engine test beds that are available for developing and evaluating the next generation of ceramics, once the parts are fabricated.

  The Aerospace Corporation conducted a survey for the DOE Technology Development and Analysis

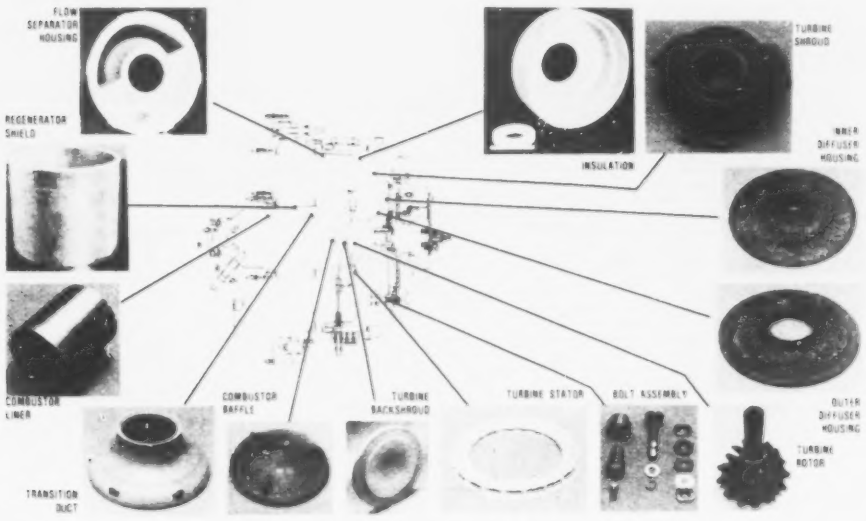


Figure 13. AGT101 Ceramic Components

Division and reported in October 1984. Eleven engine/vehicle manufacturers, five petroleum refiners, and five universities and research institutes were surveyed. The following quotation was taken from Page 5A:

> The position of automotive and fuel experts regarding the use of the AGT100 and 101 proof-of-concept engines as test beds for further development of ceramic components generally is very favorable, as is their position regarding DOE support of R&D for gas turbines in the heavy duty transportation sectors. Those in favor of the first activity (86 percent) see AGTs as having potential because of their multifuel capability, low emissions, and competitive fuel economy. They emphasize that only in an actual engine environment can engine components be subjected to the combined thermal and speed related stresses, and the interactions with other components that are required to evaluate new materials.

- The successful ceramic suppliers should be funded to fabricate parts of the AGT configuration. To successfully develop the parts, it would take the same type of iterative give-and-take design and development effort learned during the AGT program.
- Once the parts are fabricated, the AGT test rigs and engine test beds would be used to further develop and evaluate the new ceramics.
- Such a program should be initiated in FY87 to complement the current DOE and NASA generic ceramics programs. This would bring the next generation of ceramics closer to the level of maturity that industry could, with confidence, utilize for automobile gas turbines and many other applications (Figure 15).

- NASA/DOE INITIATING SECOND GENERATION CERAMICS DEVELOPMENT
- AGT PROGRAM OFFERS ALREADY PAID-FOR TEST RIGS AND ENGINE TEST BEDS FOR DEVELOPMENT AND EVALUATION OF THE SECOND GENERATION CERAMICS
  - RECOMMENDATION OF INDUSTRY AND UNIVERSITIES* FROM DOE/AEROSPACE SURVEY CONDUCTED IN 1984
- INITIATE PROGRAM IN FY87 TO HAVE INDUSTRY MAKE SECOND GENERATION CERAMIC PARTS FOR DEVELOPMENT AND EVALUATION IN AGT TEST RIGS AND ENGINE TEST BEDS

*86 PERCENT FAVORED

Figure 15. Future Development Direction

IX. What If We Don't Go Forward?

- Ceramics development in this country will slow dramatically. Since the technology is still considered long range and high risk, U.S. industry will devote limited resources to bring ceramics to production status.
- Foreign competition will bypass U.S. industry and offer ceramics for many applications before our industry does. Ceramics development is a national goal in Japan. Universities, industry, and the government seem to have a well-organized effort.
- A return of the fuel crisis could find the U.S. auto industry ill-prepared, without alternative fuel efficient and multi-fuel-burning power plants (Figure 16).

- U.S. CERAMICS DEVELOPMENT WILL SLOW
- FOREIGN COMPETITION WILL BYPASS U.S. CERAMICS TECHNOLOGY
- RETURN OF FUEL CRISIS WOULD FIND U.S. AUTO INDUSTRY WITHOUT ALTERNATIVE FUEL-EFFICIENT AND MULTI-FUEL BURNING POWER PLANTS

Figure 16. Lack of Future Development Would Prove Detrimental

X. What Do We Recommend?

- Government and industry should continue to fund the AGT program in FY86, at least at the FY85 level.
- Government should continue to fund NASA- and DOE-sponsored generic ceramics programs at least through 1990.
- Government should initiate a second-generation ceramics development and evaluation program in FY87, utilizing existing paid-for AGT test rigs and engine test beds (Figure 17).

- FUND AGT PROGRAM IN FY86 AT LEAST AT FY85 LEVEL
- CONTINUE NASA/DOE GENERIC CERAMICS PROGRAMS THROUGH 1990
- INITIATE SECOND GENERATION CERAMICS DEVELOPMENT AND EVALUATION PROGRAM IN FY87 UTILIZING EXISTING PAID-FOR AGT TEST RIGS AND ENGINE TEST BEDS

Figure 17. Recommendations

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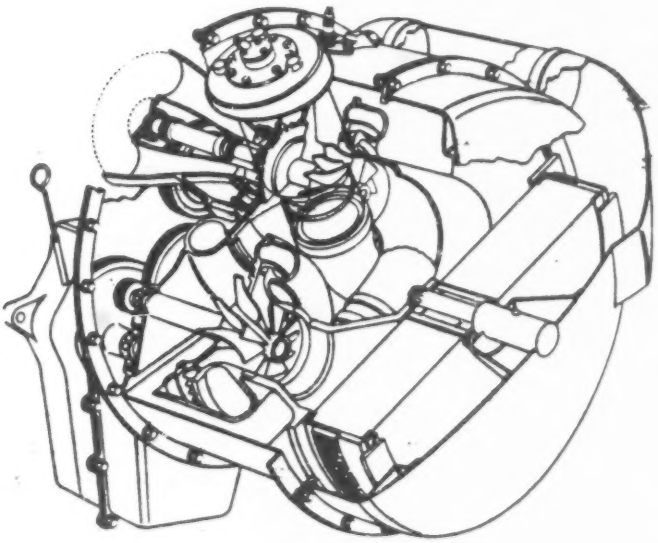
GAS TURBINE DIVISION
General Motors Corporation
P.O. Box 420
Indianapolis, Indiana 46206-0420

Testimony of General Motors Corporation on the Department of Energy Advanced Gas Turbine Technology Contract presented to the House Subcommittee on Transportation, Aviation and Materials

Committee on Science and Technology



presented by
Harold E. Helms
Chief Project Engineer
Allison Gas Turbine Division
Power Products and Defense Operations Group

27 February 1985

Allison
GAS TURBINE DIVISION
General Motors Corporation

HAROLD E. HELMS, Chief Project Engineer--Vehicular Turbines

Education

B.S. in Engineering Mechanics, Purdue University, 1948
M.S. in Engineering Mechanics, Purdue University, 1950

Work History

1952 to Date: Allison Gas Turbine Division
Power Products and Defense Operations Group
General Motors Corporation, P.O. Box 420
Indianapolis, Indiana 46206

- o Chief Project Engineer
- o Chief--Regenerator Systems
- o Program Manager--NASA QCSEE Program
- o Chief--Analytical Mechanics
- o Section Head--Stress and Heat Transfer
- o Supervisor--Rocket Nozzles and Cases
- o Deputy Leader--Allison/Rolls Royce Joint Project
- o Senior Project Engineer--T40 Engines, T56 Engines

1950 to 1952: Engineer, Argonne National Laboratory, Lemont, Illinois

Responsibility/Experience

Mr. Helms is responsible for advanced technology vehicular engines at Allison. This includes the following: AGT 100 Project--DOE/NASA contract, Fuel Cell Advanced Technology Engine and Coal Burning Turbines.

The AGT 100 program being conducted for DOE/NASA was planned and is directed under Mr. Helms' leadership of the Allison, Pontiac, Carborundum, GTE, Corning team. Ceramic materials technology is the major thrust of this program, and Mr. Helms is a recognized leader in the application of ceramic components in heat engines.

Analytical Mechanics, including stress analysis, heat transfer, vibrations, weights, and computer analysis, were directed by Mr. Helms.

Turbine cooling, including convection, film, and transpiration cooling methods, were implemented and developed under Mr. Helms' direction. Lamilloy, an Allison invention, was conceived and developed under his direction.

Mr. Helms prior experience includes work on rocket motor cases and nozzles, turboprop, turbofan, turboshaft, and turbojet engines at Allison. Mr. Helms also worked on the Atomic Energy Commission reactor project for the Nautilus submarine.

Allison
GAS TURBINE DIVISION
General Motors Corporation

INTRODUCTORY REMARKS

Thank you, Mr. Chairman, for this opportunity to present a status report on the General Motors-Allison Gas Turbine Division "Advanced Gas Turbine Technology Project" supported by Department of Energy (DOE) funding and contracted through the National Aeronautics and Space Administration (NASA) Lewis Research Center. I am Gene Helms, Chief Project Engineer, and this project responsibility falls under my cognizance. Today I have prepared a summary of activities for 1984 and a projected 1985 list of activities. I observe both positive and negative results in our 1984 activities and feel that 1985 has started on a positive note in this high risk, "high technology" project.

OBJECTIVES AND KEY TECHNOLOGIES

The Allison Advanced Gas Turbine (AGT) Technology project has objectives that include the demonstration of a "proof-of-concept" automotive engine that will have the capability of producing 30% improvement in fuel economy in Pontiac A6000 or Fiero automobiles, will operate on alternate fuels, and will meet 1985 and beyond automotive emission requirements. In addition, competitive initial and life cycle costs, reliability, performance, and noise and safety criteria for automobiles are goals for this project. Figure 1 shows the project objectives and the proof-of-concept engine applicable in the Pontiac A6000 and Fiero automobiles.

Marketplace criteria are used at General Motors in planning and implementing high risk, high payoff, long-range technology projects. Allison adhered to these criteria in planning the AGT 100 project. These criteria are cost, performance, and reliability.

Key technology areas identified and being pursued vigorously are:

- o ceramic turbine components
- o small scale turbine aerodynamics

Ceramic Turbine Components

Ceramic component development is the new and innovative technology area that will determine the future practicality of automotive gas turbines. It is necessary that ceramic components with high temperature capability replace the prohibitively expensive superalloy metals currently used in gas turbine components. Superalloy costs are prohibitive because they contain significant levels of strategic materials such as cobalt, chromium, nickel, molybdenum, tungsten, and manganese. None of these costly, strategic materials are found in the silicon carbide, silicon nitride, oxides, and silicate components being developed in the AGT 100 project.

Aerodynamics

Small-scale turbine aerodynamics are important because the automotive gas turbine engine has smaller components than ever before employed in a high performance production turbine engine. Simultaneously, the automotive application requires high aerodynamic component efficiencies over a broad power range, with the highest efficiency required at part speed and power conditions. The average automotive gas turbine power usage is 14 hp (for this 100-hp engine) and most automobiles never use maximum power, since it is incorporated for acceleration, hill climbing, and other emergency power operations. This contrasts with aircraft, industrial, and heavy duty turbine engines, which operate predominately at 50% to 100% power level, but do not have similar acceleration and other emergency power requirements.

ENGINE TECHNOLOGY EVALUATIONS

Heat engine experience has shown that component technology is only valid when proven in an actual engine operational environment. This fact of development has been obvious in all engines because of our inability in rigs to duplicate the unique transient (a key to ceramic component suitability) operating characteristics of an actual engine and to reproduce working interrelationships between components associated with aerodynamics, heat transfer, control, and mechanical factors. For these reasons, proof-of-concept engines complemented with rigs, carefully chosen for screening and proof testing, are included in this project to prove that new ceramic and aerodynamic component technologies have been established in sufficient depth for usefulness to industry. Allison has designated its engine the AGT 100. Figure 2 is a recent photograph of the AGT 100 engine on the test stand in Indianapolis. This engine weighs less than 300 lb, develops 100 hp, has two shafts, is regenerative (recovers waste exhaust heat), and is compatible with any type of transmission (manual, automatic, or continuously variable). The engine and accessory arrangement can be used interchangeably to replace current General Motors 2.8 Liter V6 or 2.5 Liter L4 spark ignition engines in mid-size automobiles (approximately 3000-lb weight class). Allison assessments of reliability, performance, control, and cost trade-offs have favored the two-shaft gas turbine engine for vehicle applications where constantly changing power requirements are placed on the power train.

PROJECT TEAM

Pontiac Motor Division of General Motors is an Allison partner in the AGT 100 project. They have established the STE6000 and the new Fiero automobile as candidate applications for the AGT 100. Pontiac provides the expertise that ensures producibility, marketing, and cost analysis and gives continuing guidelines to Allison for achieving engine and component improvements to meet marketplace requirements.

Allison has worked on ceramic materials development projects sponsored by DOE/NASA since 1976. The Carborundum Company, Corning Glass Works, and GTE Laboratories have been prime suppliers for Allison of ceramic components on NASA/DOE projects including the current AGT 100 project. More than 9,400 hr of 404 engine running has been accomplished with Corning regenerators, Carborundum

silicon carbide, and GTE silicon nitride flow-path parts in the DOE/NASA CATE (Ceramic Application in Turbine Engines) project. The AGT 100 project enlarges on the CATE technology base in ceramic components, and additional companies supplying ceramic components for the AGT 100 project are as follows:

AC Spark Plug Company, Flint, MI
Norton Company, Worcester, MA
Pure Carbon Company, St. Marys, PA
Coors Porcelain Company, Golden, CO
Asahi Glass, Japan
Kyocera Company, Japan
NGK Insulators, Japan
Feldmuhle Company, West Germany

Allison subcontracting practice has placed development and parts subcontracts at only American ceramic suppliers. Foreign purchases have been only for parts and these have been used for comparative purposes to date.

PROJECT STATUS

1984 was a year of significant achievement at Allison in the AGT 100 project. Highlights of 1984 are as follows (see Figure 3):

- o Advances in ceramic component processing at ceramic component suppliers occurred.
- o Engine testing that increases total engine test time to over 225 hr was achieved.
- o Nine ceramic components were successfully engine tested with iterations on geometry and operating conditions.
- o Two new rigs were installed and are operational for improved component screening and proof testing.
- o Silicon carbide scrolls were obtained from Carborundum and Norton Company, and initial rig tests were made on the Carborundum scroll.
- o Silicon carbide rotors from the Carborundum Company were acquired, spinned in a qualifying rig, and engine tested with limited success.
- o Silicon nitride rotors from the Kyocera Company were acquired and have been spin tested to 160% speed (138,000 rpm) without failure (these rotors will be engine tested in 1985).
- o Participation in technical society meetings and on advisory boards for ceramics took place.
- o Improved design methods were implemented for AGT 100 components.

External to the AGT 100 project, but within General Motors, additional testing of ceramic materials and alternate fuels occurred.

- o An automotive gas turbine successfully ran on dry micronized coal at General Motors Engineering Staff (Ref: ASME paper 83-GT-183). Additional testing increased total engine running time in a 1979 Cadillac Eldorado to over 310 hr, proving the feasibility of clean coal as an alternate turbine fuel.

1985 promises to be a rewarding year with anticipated accomplishments to include:

- o additional advances in ceramic component processing
- o accelerated engine testing and rig testing of components to turbine inlet temperatures in excess of 2000°F
- o methanol evaluation on the AGT 100 combustor
- o iterations of design, processing, and engine evaluation of ceramic components

Ceramic components that will be rig or engine tested in 1985 include the Corning regenerator seal platform and duct, the Corning regenerator, Allison regenerator seals (not shown), Kyocera thermal barriers, Carborundum SiC combustor body, combustor dome (not shown), combustor (not shown), and Carborundum SiC turbine vanes that have already been tested in the engine. Metal shafts will be attached to the ceramic rotors for engine evaluations. The turbine scroll assembly including the two backplates shown will be rig tested in 1985 with engine testing planned in 1985 (see Figure 4).

Engine testing accomplished in 1984 has shown 36 hp at the designed 2000°F turbine inlet temperature, which is over 80% of the designed value. The balance (to 46 hp) is related to reducing clearances, improving cycle leakage, and other achievable changes that are being made with evolving engine development. Improvement in reliability of ceramic components is seen as the pacing technology to a successful production automotive gas turbine. This emphasizes the importance of continuing the AGT 100 project and other advanced ceramic component development programs such as the "Ceramic Initiative Programs" being initiated at Oak Ridge and NASA Lewis Laboratories.

AGT 100 SCHEDULE AND FUNDING

In 1984, the AGT 100 project spent $9.0 million, compared with a planned $11.5 million expenditure. Allison more than doubled its cost share on the remaining portion of this project in 1984. Figure 5 shows the schedule for a funding level of $8 million in 1985 and 1986. This is less than what was spent in 1984 and 20 percent less than had been planned for these years.

As often occurs in high risk programs of this nature, ceramic component development has not progressed as fast as originally planned. However, the schedule through 1986 is based on component technology that has been or will be achieved and, therefore, represents a realistic outlook. We would expect that post-1986 activities, if any, would involve a continuation of engine endurance and performance testing to provide proof of concept relative to ceramic component technology. Such proof of concept would appear to be compatible with the DOE/NASA ongoing ceramic initiative programs.

Figure 1. Advanced Gas Turbine Technology Project.

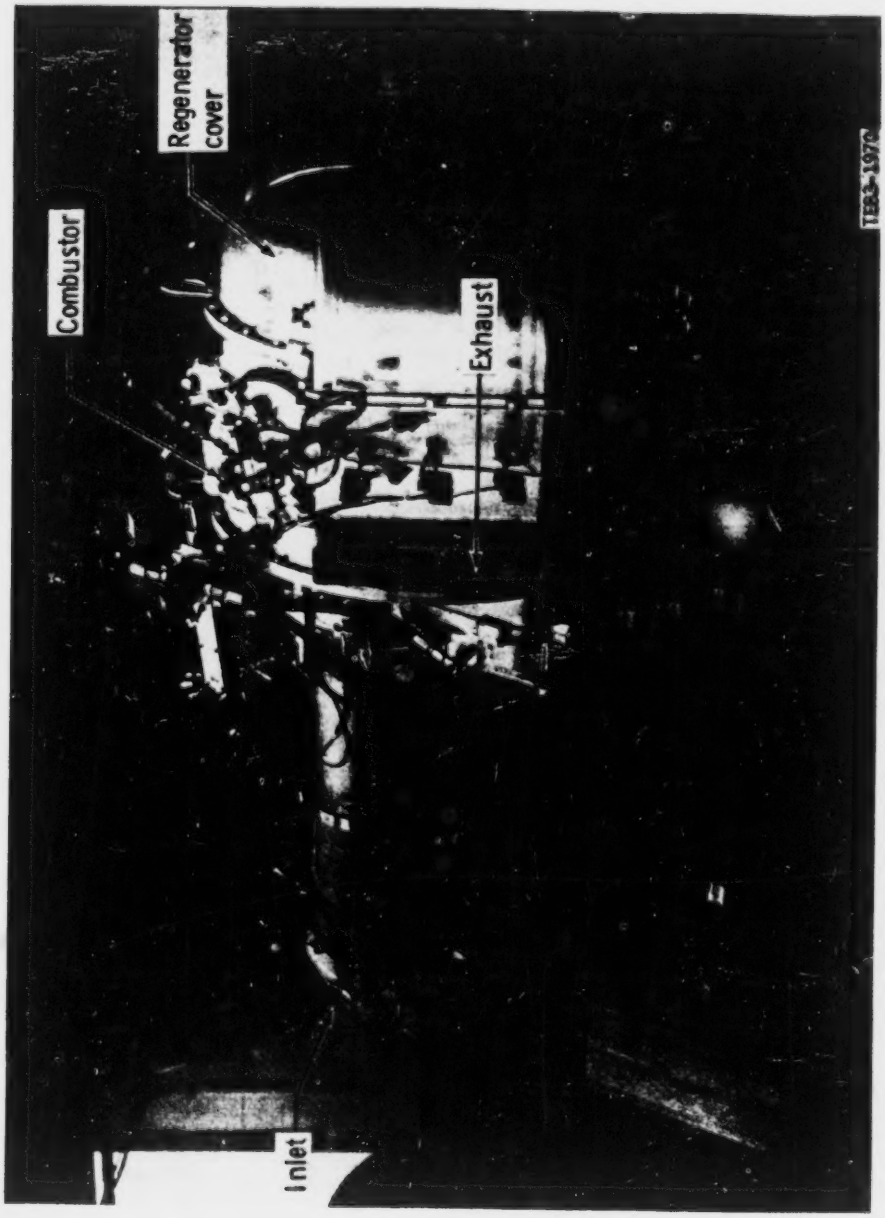


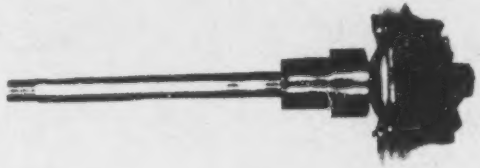
Figure 2. AGT 100 engine.

TOTAL HOURS	• 1984 TIME APPROX. TRIPLE THAT OF 1983 • 223 TOTAL ENGINE HOURS
HOURS PER BUILD	• 38 HOURS ON SINGLE NUMBERED BUILD • 66 HOURS ON SINGLE TURBOMACHINERY BUILD
EFFECTIVE MOD'S.	• CERAMIC BULKHEAD AND TURBINE EXHAUST INTERFACE • VISCOUS DAMPED COMPRESSOR BEARING
HI-SPEED TESTS	• 1:07 HRS CONTINUOUS AT 100% GASIFIER RPM • 1900°F TURBINE TEMPERATURE • 35 SHP AT CORRECTED STANDARD CONDITIONS
RELIABILITY	• CONTINUED ABSENCE OF MAJOR FAILURE • ACCELERATING ENGINE TIME
TEST OPERATIONS	• DEDICATED TEST CELL • IMPROVED INSTRUMENTATION INSTALLATIONS • REDUCED SIZE TEST CREW
ENGINE CERAMICS	• TYPICAL HEAT-UP RATES • COMBUSTOR AND REGENERATOR HIGH TIME PARTS • ADDITIONAL CERAMIC CONVERSIONS

TE85-711

Figure 3. AGT 100 engine test accomplishments.

CERAMIC ROTOR



CERAMIC SCROLL

FLOWPATH DIAGNOSTICS

- SPLIT FLOWPATH AND HELIUM SEEDING
- CO_2 TRACER GAS TECHNIQUE
- TURBINE NOZZLE ROTATING FLOW CALIBRATIONS

TE84-712

Figure 4. Near-term AGT 100 engine test plans.

Allison GAS TURBINE DIVISION General Motors Corporation

GM

OUTLOOK

The new technology coming from the current AGT 100 project is helping to accelerate development of structural ceramic components in heat engines. Gas turbines with ceramic components for tanks, cruise missiles, and industrial engines are receiving significant interest. Allison continues to study the AGT 100 or growth versions of it for many vehicular, marine, aircraft, and industrial applications for both military and commercial markets. Carrying this project to completion will provide an initial technology in ceramic components and small aerodynamic components that offers advanced heat engines for a multiplicity of applications.

Mr. Chairman, this concludes my prepared remarks. Thank you for this opportunity to update you on the General Motors-Allison AGT 100 project. I will be pleased to answer questions you or your committee may have on this project.

Mr. LEWIS. I would like to call now Mr. Hudson of Eagle-Picher to testify. Mr. Hudson, you can summarize your statement.

STATEMENT OF RAY HUDSON, EAGLE-PICHER, JOPLIN, MO, ON BEHALF OF BATTERY DEVELOPMENT FOR ELECTRIC VEHICLES

Mr. HUDSON. Thank you. I represent Eagle-Picher Industries. We are a wholly owned American corporation with our corporate offices in Cincinnati, OH. We as a corporation have 21 operating divisions. I represent the electronics division which is headquartered in Joplin, MO.

Mr. HUDSON. Our basic endeavor in the Department of Energy program to date has been that in the area of battery development. We are a battery manufacturer which fall into two prime categories; the special purpose batteries which services the military and aerospace type industries and commercial batteries. The special purpose batteries have been applied to the military primarily in the military defense systems of the country. Aerospace programs are those programs which are seen around the room here and I'm happy to say that we have provided batteries for all the space exploration programs.

The commercial batteries is primarily concentrated in the maintenance free lead-acid and the lithium ambient temperature batteries. The lead-acid batteries primarily serve the emergency lighting market, the computer memory dump systems, the electric tool, and most recently the electric toy market.

The division which I represent also has the responsibility for developing of the advanced batteries for electric and electric/hybrid vehicle applications.

As the oil crisis came into being in the early 1970's, we as a corporation reviewed the candidate battery systems which may have applicability to the electric vehicle application. We categorically divided those up into three subcategories: that of the present day battery systems, a midterm battery system, and an advanced battery system. In the present day battery system which would seem, logically, to serve a market up through the 1990 time period, we place present day flat plate lead-acids and the tubular lead-acid batteries. Midterm was primarily the nickel based systems; nickel-iron, nickel-zinc, nickel-cadmium, and then the flow battery systems; zinc-chlorine and zinc-bromine. In the advanced battery system which may come into feasibility after the year 2000, we placed the molten salt battery systems; primarily sodium sulfur and the lithium/metal sulfide, and the metal air systems; specifically iron-air and aluminum-air as the candidate systems that may serve the electric vehicle.

Depending on funding levels we targetted the time frames which are depicted in the written testimony as being unclear relative to the oil crisis and what that may mean to alternative forms of transportation. Subsequently, we then made the decision to pursue one battery type in each of the dividing categories. In the present category, we decided to pursue the tubular plate lead-acid concept. This gave the advantage over the standard flat-plate technology of better energy density which relates to increased vehicle range and better cycle life, which is tied to operating costs of the vehicle. As

it soon became apparent that the range of electric vehicles would be in excess of 30 miles, we abandoned the tubular plate lead-acid concept.

In the mid-term category, we chose the nickel-iron system primarily because of its superior energy density and its long life characteristics. Historically we have been in nickel-zinc batteries primarily for submarine and life-support operations. We find that nickel-zinc batteries generally give us very poor cycle life. The flow systems—the zinc-chlorine and zinc-bromine—are systems much like a refrigeration system and we could not envision a flow battery system being applicable to the mobile operation.

The nickel-cadmium battery, although it possessed good cycle life, seemed to have definite shortcomings in the areas of specific energy and ge energy density. The cadmium electrode has a problem with memory effect and cadmium also happens to be one of those materials that is on the critical material list.

In the advanced area, in the molten salt battery area, we chose to pursue the lithium-metal sulfide. It was primarily chosen over the other candidates systems because of its high energy density its good cycle life, and its safety to the passenger and surrounding community.

The electric vehicle offers to the nation the potential of an alternative form of transportation. This alternative form of transportation would greatly reduce our dependence on foreign oil.

Generally these alternative modes of transportation are divided into two categories: the commuter-type vehicle and the fleet-type vehicle. A number of studies have been conducted by a number of organizations in the country that say that over 90 percent of the trips we make in our automobiles are less than 90 miles from home. Potentially, there is in excess of 20 million of the commuter-type vehicles that could be replaced by electric vehicles and over 50 percent of the fleet vehicles which is on the order of 7–8 million vehicles that could be replaced by electric vehicles that have a range in excess of 60 miles.

Once the battery is fully developed, this battery system can be viewed in the same light as we talked in petroleum resources today: It should be there if we need it. However, as we sit here today, certain technical hurdles must be overcome prior to the electric vehicle becoming a viable, economically acceptable alternative to the IC vehicle.

Certainly the battery is the weak link in a required vehicle system. Therefore we feel quite strongly that a priority should be placed on battery development in looking at this important alternative transportation.

Being available at a cost that is economically viable is foremost in everyone's mind. Whether that cost is up front to the everyday public person or whether it is an amortized life cycle cost to the fleet vehicle user becomes increasingly important. In today's economic environment principally where gasoline is in abundant supply, there is not a large market demand for the vehicle or an alternative method of transportation. Subsequently, there is not a lot of market push on the behalf of industry to bring the electric vehicle to the forefront. Because of this lack of market demand, the

responsibility of bringing the electric vehicle technology to the viable stage will likely fall on the Government.

Readiness is the key in the event of an oil interruption. The oil crisis in the 1970's certainly demonstrated to us as we sat in long gas lines that we do not have an alternative form of transportation. It has been our experience in the development of batteries such as we see in the space exploration programs that a period of 10 years is required to bring such technology to the forefront.

Specifically now I would like to address some remarks to the program that has been sponsored by the Department of Energy over the last few years at our facility which is the nickel-iron system.

We have been developing the nickel-iron system at Eagle-Picher Industries for the use in electric and electric/hybrid vehicles since late 1978. First one has to ask oneself, what are the advantages of the candidate battery system. Those advantages are those that you see listed; increased vehicle range and utility in excess of 60 to 100 miles, reduced maintenance costs especially to the fleet user, auxiliary equipment such as flow systems not required, no equalization is required, low life cycle cost resulting in attractive ownership cost.

Goals which we have set forth in the Base Battery Program are specific energy at 56 watt hours per kilogram, specific power relating to vehicle acceleration, energy density is the footprint which the battery can occupy in the vehicle, energy efficiency determines the cost of your fuel, cycle life is simply how many times it can be charged and discharged, and cost which is targeted at half that of the IC vehicle.

The program elements are divided into four basic areas; one, positive electrode study, two, negative electrode study, three, cell/module development effort, and four, testing.

This is one of the key electrodes of the nickel-iron system which is the nickel electrode and shows three steps in which the electrode takes form. The starting plaque is impregnated with active material leading to its final form ready for the cell structure. This positive electrode is then married with the negative electrode with a center polyvinylchloride separator in the middle which separates the electrodes. These electrodes then are ready to be put in a cell case and this is the final cell. This is the final 6-volt module which is the basic building block for any battery system. The black circles which you see on top of this 6-volt module is what we call a single point watering system. This is a very simple method of refueling your battery for the needed watering.

A number of in-vehicle tests have been conducted using the nickel-iron battery system, as we know it to date, have been tests in a transporter van. This is a second closeup look of the battery pack which is actually slung between the rails of the vehicle beneath the cargo floor. We have tested it in a Volkswagen pickup truck and the Ford F-100 pickup truck and demonstration of the viability of the electric vehicle technology.

We have also participated in the electric vehicle programs with General Motors, the Northrop Corp., and are currently involved with the Eaton Corp.

The purpose of these vehicle demonstration programs has been to clearly demonstrate the specific advantages that the nickel-iron

system offers over competing technologies and to better understand and possibly reveal potential problems from a total system standpoint as the battery is used in its intended environment.

In summary, I would like to say that battery development has not realized its goals such that vehicle and range acceleration and weight requirements are satisfied.

Specifically, in the case of nickel-iron batteries, we feel that about 60 percent of the goals have currently been reached. It is anticipated that, given the present fiscal year 1985 funding levels, the development will need to continue for a period of 4 to 5 years before these goals are fully realized.

Presently, the nickel-iron battery system is viewed as the only candidate battery system which can offer a viable alternative to the IC powered vehicle within the next 5 to 10 years.

Mr. LEWIS. Thank you Mr. Hudson. Did Mr. Boppart leave? He did. I would like to ask Mr. Helms and Mr. Nightingale to come back up for another couple of questions in just a minute.

Mr. Hudson, you made reference in your testimony about maintaining Government activity in this field. Do you agree with the DOE plan at all to wrap up this work on lead-acid and nickel-iron battery technologies, and if not, what work remains to be done.

Mr. HUDSON. I would agree that the lead-acid technology, if we categorically say that vehicle ranges in excess of 60 miles are required, the lead-acid technology does not have the capability to meet those requirements. We ourselves are lead-acid battery manufacturers and we have said that lead-acid batteries will not meet those requirements.

Certainly we don't agree with that philosophy in the case of nickel-iron batteries and we have had discussions with them along those lines. In the budget area, the goals that have been set, the budgets have been trimmed over the last 3 or 4 years since the progress we felt should have been made and expected to have been made were not able to be realized in that area. We have discussed that somewhat adamantly with the Department people and I think they realize those goals will not be met in fiscal year 1986 given the present budget levels.

Mr. LEWIS. What other kinds of battery research do you feel that DOE should pursue?

Mr. HUDSON. In understanding what the purpose of the Department of Energy is in readying the Nation in event of an oil crisis and also at the same time developing an alternative transportation source, certainly the candidate battery systems that possess a higher specific energy and long cycle life offer a larger market penetration to the electric vehicle and the electric vehicle user. Therefore, very likely, the more advanced battery systems would be those candidate systems which one should pursue.

Mr. LEWIS. Mr. Hudson, why don't you stay—Mr. Nightingale, will you and Mr. Helms come back up, please? I'm going to ask all three of you the same question. I'm sorry that Mr. Boppart had to leave.

I believe, Mr. Nightingale, you may have made this statement or a partial statement to this effect, that other factors other than performance must be overcome. I would like to hear your response to that as far as your area that you're concerned with, also Mr.

Hudson and Mr. Helms. Mr. Nightingale, why don't you respond first?

Mr. NIGHTINGALE. When I was asked the question about the performance of the Stirling engine, I emphasized the fact that that was only one of many parameters that the automotive industry looks at. There is quite a long list of them, but if I single out the two major ones, they are manufacturing costs and reliability. They're not about to pick up a new technology until they see reliability and a competitive manufacturing cost capability. In fact, we know that one of the influencing factors behind the cancellation of the Ford Stirling Program in 1978 was based on the fact that the engine that they were looking at was not manufacturable. That was one of the ingredients that went into their decision to get out of the Stirling. We have been able to turn that corner over the course of the ASE Program and come up with the MOD II, which has a low manufacturing cost. I would answer it with those two items; manufacturing cost and reliability.

Mr. LEWIS. Mr. Helms.

Mr. HELMS. I think you'll find in my testimony that we have easily identified that the three elements that you must satisfy to have a product are performance, reliability, and cost. For the automotive arena, the order in which you state those three items is up to the individual. Cost is generally a very significant driver in the automotive market place. I believe those are the three key criteria one must use in establishing the adequacy of a technology data base which I think is the role of government in these high risk, high technology programs. Cost is a very compelling factor, but equally you must meet the performance and reliability requirements of the marketplace. I've heard 60 miles mentioned in the EV discussion. We at GM have a 300-mile range as a requirement for an automobile. That's by practice and experience. Maybe that can change, but we would not today accept a vehicle that did not have a 300-mile range capability. You go jump in your automobile and one of the performance requirements we think you have is that you would like to be able to drive from Chicago to Louisville without having to stop and charge your battery or fill your tank. That's an example of a performance requirement. Similarly, we believe that when you buy a vehicle from us that you're going to want to drive that vehicle some extended period of time without having to fix or replace a component. So, the reliability is a critical element and a criteria that we use in getting a data base ready for the marketplace. Those three key elements are the criteria to judge a product by and to judge a technology base with as you address applicability.

Mr. LEWIS. Mr. Hudson, as far as the EV, what would you consider factors other than performance areas that must be overcome?

Mr. HUDSON. I categorically have three of them. One is a manufacturing base which is certainly not in place today relative to much of the electric vehicle componentry parts. Certainly there are a lot of programs in place looking at conversions of present IC type vehicles. Therefore, a manufacturing base is No. 1. Cost and reliability, I categorically put those together. You cannot have low cost unless you have good reliability. At least from a battery standpoint, those two go hand in hand. The third category that I have is

that of safety. Certainly DOT has certain requirements relative to onroad type vehicles and in order to participate and have onroad type venicles, I think the electric vehicle has to satisfy those safety requirements and those have to be demonstrated.

Mr. LEWIS. One last question—what do you think DOE could do better in your respective technologies and programs?

Mr. HELMS. I believe I'm seeing signs that are very favorable. Those include such things as planning with industry advanced programs. Also new programs that industry would like to do. In the past, many programs have been planned without the benefit of adequate input from industry. I see very favorable steps—I would compare again to the Japanese scenario—where I see a very close working relationship between government, industry, and the world of academia. I think that's starting to unfold in our system. I encourage that. A recent development at DOE is that it is now possible for industry to have a national laboratory—DOE sponsored—work with industry to address certain specific problems. In past years, that has not been possible. It is now and I thank you and other Members of Congress that have helped to make that possible. Additional steps in that direction I believe would be very desirable from our country's standpoint—not just for General Motors—and for every industry as they address their technological problems.

Mr. LEWIS. Mr. Nightingale.

Mr. NIGHTINGALE. I think that besides zeroed out each year and having to contend with my staff at home when they hear this, I think the major element that DOE could do for us is to take advantage of this rather broad base of applications that we're finding that the Stirling engine applies itself—in other words—maybe further extension of the ITEP program that I talked about, moneys that would enable us to deal with the agricultural industry, the Army, the Air Force, the Navy co-op through interagency agreements, which is what we're starting to work on. I think more support in those areas because I think then, and only then when we have a broad base application, would the technology be accepted in some niche, be it small vans or automobiles or somewhere else. I think that is one area where I think a little more aggressiveness on the part of the DOE would help immeasurably.

Mr. LEWIS. Mr. Hudson.

Mr. HUDSON. I agree with Mr. Helms. I think that industry participation is certainly a key element which had not been there in the past. We do see that starting to come to the forefront now. I think it would be very good such that a lot of the technology that has been pursued in the past had been kept within the DOE, the national laboratories, and the academia sector, and industry has not participated. If those technologies which are being looked at are going to come to the forefront, industry has to be involved and I feel quite strongly that industry should be in on the initial planning stages of those kinds of programs also.

Mr. LEWIS. Thank you, gentlemen, for appearing before the committee and providing the testimony. It's all a matter of record, and if there's no further business the committee will stand adjourned until call of the Chairman.

[Whereupon, at 4:15 p.m., the subcommittee recessed.]

[The prepared statement of Mr. Hudson follows:]

TESTIMONY

Battery Development

for

Electric Vehicles

at

Eagle-Picher Industries, Inc.

Joplin, Missouri

Eagle-Picher Industries, Inc. is a wholly owned American corporation with corporate headquarters in Cincinnati, Ohio. The corporation is composed of twenty-one (21) operating divisions. It has seventy (70) plants in the United States, Canada, and West Germany. With few exceptions, no two plants produce the same product and each plant exists independently under its own management. Eagle-Picher is a Forture 500 Company and currently has an annual sales in excess of $600 million.

The Electronics Division of the Corporation which is presenting this testimony, is chartered with the responsibility for all battery activities of the Corporation. The base for the battery activities is divided between 1) special purpose batteries and 2) commercial batteries. The special purpose batteries support the military and weapons application as well as the space exploration programs. The commercial batteries, primarily maintenance free lead-acids and ambient temperature lithiums, serve the emergency lighting, computer standby power, electric tool and toy markets. The

Electronics Division has the responsibility for the development of batteries for the electric and electric/hybrid vehicle application.

As the impending oil crisis came into being in the early 1970's, Eagle-Picher reviewed the possible candidate battery systems which could feasibly serve this application. The candidate systems which were reviewed were subsequently placed into the following categories:

Present (1975-1990)

Lead-Acid (Tubular)

Lead-Acid (Advanced Flat-Plate)

Mid-Term (1985-2000)

Nickel-Zinc

Nickel-Iron

Nickel-Cadmium

Zinc-Chlorine

Zinc-Bromine

Advanced (1995-2020)

Sodium-Sulfur

Lithium/Metal Sulfide

Iron-Air

Aluminum-Air

The overlap in time dates indicate the uncertainty at that time of the need or utilization of electric vehicles. If an oil crisis did or in the future again, come into being certainly more effort would be expended in

bringing the more advanced batteries into being at an earlier time. Eagle-Picher made the decision to focus and subsequently pursue one battery system in each of the divided categories. There were as follows:

Present

Lead-Acid (Tubular)

Mid-Term

Nickel-Iron

Advanced

Lithium-Metal Sulfide

The rationale which went into that decision making process is briefly summarized below:

PRESENT: The tubular plate lead-acid was selected as it could provide slightly better energy density and slightly better (approximately 10%) cycle life than the flat plate concept. However, as it soon became apparent that the required range of the electric vehicle would be in excess of 30 miles/day, coupled at the same time with a declining market in traction batteries, the decision to terminate participation in the tubular plate battery business was made.

MID-TERM: In this category the nickel-iron battery was chosen over the other candidates due to its overall energy and power characteristics plus its lifetime capabilities. Nickel-zinc was discarded because of its poor cycle life. The zinc-chlorine and zinc-bromine systems are "flow" type systems which require auxillary pumps to circulate the reactants and there-

fore seemed more appropriate for the stationary, load leveling, application rather than the mobile one. Nickel-cadmium, although possessing good cycle life, is too low in specific energy and energy density to be of use in the mobile application. Cadmium is also a material which is in short supply and is on the "critical" resource list.

ADVANCED: The lithium-metal sulfide system was chosen over the other candidate systems because of its high energy density, good cycle life potential, no material availability problems, and system safety to the passenger and surrounding community. Sodium-sulfur appeared to have many material compatibility problems as well as a safety concern to the passenger and surrounding community. The metal-air systems have a poor energy efficiency and resolution to this deficiency seemed very difficult.

The electric vehicle offers to the United States the potential of an alternative form of transportation which would greatly reduce our dependence on imported oil supplies. This alternative mode of transportation falls into two (2) areas: 1) the commuter type vehicle and 2) the fleet type vehicle used primarily for service, maintenance, or delivery. A number of studies have been conducted which verify that over 90% of an average persons trips in a commuter type vehicle are less than 90 miles in length and fleet users have greater than 50% of their vehicles which traverse less than 60 miles/day. In the cummuter vehicle it has been estimated that a potential replacement in excess of 20 million vehicles exists whle in the order of 7-8 million replacement potential exists in the fleet user area. If an oil crisis once again comes into being, an alternative fuel such as "electric"

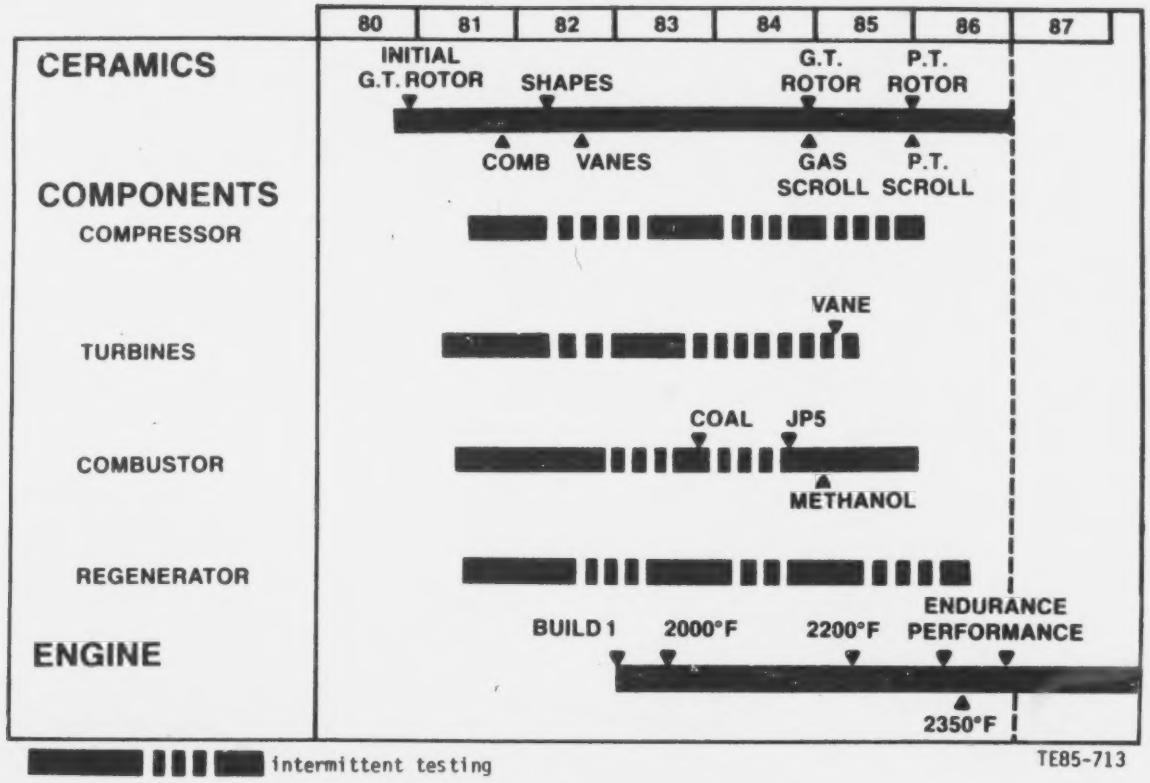


Figure 5. AGT 100 project schedule.

becomes increasingly important to our transportation system. The battery when fully developed can be viewed in the same light as petroleum reserves.

However, certain technical hurdles must be resolved prior to the electric vehicle becoming a viable, economically acceptable alternative. Currently the battery is the "weak link" in the required electric vehicle system and therefore should receive a higher priority relative to work being done to resolve the shortcoming. As mentioned previously vehicle range in the order of 60-90 miles is a must. Being available at a cost which is economically viable is the bottom line. In today's economic environment, principally where gasoline seems to be in plentiful supply, there is not a large market "pull" relative to the needs of an alternative method of transportation. Subsequently there is not a large market "push" on the part of industry to bring the electric vehicle to the forefront. Because of today's lack of market demand, the responsibility of bringing the electric vehicle technology to the "viable" stage will likely fall on the government. Readiness is the key in the event of an oil availability interruption. The oil crisis of the 70's demonstrated we did not have a viable alternative transportation method. It has been our experience that a period of ten (10) years minimum is required from the time serious development is initiated until the time the product, in this case the battery, is available on a limited basis.

Eagle-Picher Industries, Electronics Division, is developing the nickel-iron battery system for use in electric and electric/hybrid vehicle propulsion. Eagle-Picher has been developing the nickel-iron system for the

vehicle application since late 1978. The initial development program as well as subsequent development efforts have been sponsored by the U. S. Department of Energy via the Argonne National Laboratory. The nickel-iron battery offers to the user the following advantages:

1) Increased vehicle range and vehicle utility - the nickel-iron system has the capability to provide the vehicle with a range of 60-100 miles depending on vehicle payload and size as well as driving conditions.

2) Reduced Maintenance Costs - the single point watering system which has been developed concurrently with the base technology reduces the need for time consuming battery watering.

3) No Auxillary Equipment Required - as the nickel-iron is a stand alone aqueous battery system no auxillary pumps, etc. are required for its operation. A simple battery charger, either on board or in the garage, is all that is required for recharging.

4) No Equalization is Required - testing to date has shown that no unbalance of cells results after repeated discharges of the battery under the required vehicle profile.

5) Increased Reliability - with the extreme ruggedness the system offers relative to over discharge, over charging, and operating at temperature extremes, the overall reliability from the total battery standpoint is very good. This is not to imply the total reliability required of the vehicle is satisfied or proven today.

6) Low Life Cycle Cost - the long life of the nickel-iron system makes the cost of ownership very low in that battery replacement is not envisioned over the lifetime of the base vehicle.

The goals which have been established for the battery are listed below:

Specific Energy	-	56 WH/Kg
Specific Power (peak)	-	104 W/Kg
Energy Density	-	120 WH/Liter
Energy Efficiency	-	70% Minimum
Cycle Life	-	800 Minimum
Cost	-	$70/KWH (1982 Dollars)

Specific energy relates to vehicle range and involves the total weight of the battery which can logically be carried in the vehicle. Peak specific power relates to acceleration in the vehicle. Acceleration of the electric vehicle must conform to minimum Department of Transportation requirements. Energy density relates to the volume the battery can occupy in the allowed vehicle space. Energy efficiency is the measure of total kilowatt-hours achieved during discharge versus total kilowatt-hours charged back into the battery. Cycle life is defined as the number of times the battery can be charged and subsequently discharged to 80% of its rated capacity. Cost is of course the bottom line in any user's mind. Cost can be viewed as an up-front one time cost as in the case of the commuter vehicle or as a life cycle cost as likely will be the case of the fleet user.

Development efforts to date have been very successful in the drive to achieve the levels of energy density, power, and cycle life necessary to make the electric vehicle a viable alternative to the IC powered vehicle. Eagle-Picher through a cooperative agreement with the Swedish National Development Company/SAB-NIFE has brought into the nickel-iron program

advanced iron electrode technology which was not previously available in the United States. This technology is now available at our Joplin facility. This iron electrode technology coupled with Eagle-Picher's long standing nickel electrode technology has provided the base from which the present battery system evolved. To date, the base development program(s) have been funded primarily by the U. S. Department of Energy and supplemented by cost-sharing arrangements by Eagle-Picher. The development program as scoped to date has concentrated on the characterization, fabrication, and testing of the required electrodes, the fabrication and testing of full-scale cells, and finally the fabrication and testing of full-scale (270AH) six (6) volt modules. Electrodes of final configuration have now reached a lifetime of 2500 cycles. Full scale cells have presently exceeded 1200 cycles and continue to track the individual electrode tests almost identically. Most recently modules representing latest state-of-art technology have been placed under test which are demonstrating in the area of 55 WH/Kg. The significance of this is two fold: First it demonstrates marked progress in the area of high specific energy, and secondly it demonstrates technology which lends itself to cost effective production in volume quantities. Lifetime of this technology is currently still under evaluation.

As a part of the overall Eagle-Picher Nickel-Iron Program, a number of in-vehicle engineering tests have been conducted with prototype nickel-iron batteries. The purposes of these programs are: 1) to clearly demonstrate the specific advantages the nickel-iron battery system has to offer over competing technologies and 2) to better understand and possibly reveal poten-

tial problems from a total systems standpoint as the battery is utilized in its intended environment. Tests have been completed with the Volkswagen transporter van, sedan, and pickup, and the Ford Escort and pickup. These tests have generally shown an increase in vehicle range of 2-3 times (vehicle dependent) when utilizing the nickel-iron as a direct replacement for the standard lead-acid battery pack. In addition, the Northrop Corporation is currently operating a fleet of twelve (12) vehicles utilizing the Eagle-Picher Nickel-Iron system. These tests are aimed at demonstrating the appliciability of the nickel-iron system in fleet applications. Cost effectiveness with respect to battery replacement and maintenance shall also be demonstrated during the course of this test and evaluation program.

In summary the battery development effort not yet realized its goals such that the vehicle range, acceleration, and weight requirements are satisfied. Specifically in the case of nickel-iron the development is deemed to be about 60% complete. It is anticipated, given FY-85 funding levels, the development should continue for an additional 4-5 years.

Presently the nickel-iron battery is viewed as the only candidate system which can offer a viable alternative to the IC powered vehicle within the next 5-10 years.

ADDENDUM

COPY OF VIEWGRAPHS

EAGLE PICHER
COUPLES DEPARTMENT
JOPLIN, MISSOURI

ADVANTAGES OF THE NICKEL-IRON SYSTEM

* INCREASED RANGE (2X) AND VEHICLE UTILITY
* REDUCED MAINTENANCE COST
* NO AUXILIARY EQUIPMENT REQUIRED
* NO EQUALIZATION REQUIRED
* INCREASED RELIABILITY
* LOW LIFE CYCLE COST

EAGLE PICHER

COUPLES DEPARTMENT
JOPLIN, MISSOURI

PROGRAM GOALS

SPECIFIC ENERGY	-	56 WH/Kg
PEAK SPECIFIC POWER	-	104 W/Kg
VOLUMETRIC ENERGY DENSITY	-	120 WH/LITER
ENERGY EFFICIENCY	-	70 %
CYCLE LIFE	-	800 CYCLES
COST	-	$ 70/KWH

EAGLE PICHER
COUPLES DEPARTMENT
JOPLIN, MISSOURI

PROGRAM ELEMENTS

* POSITIVE ELECTRODE STUDY
  - A) PLAQUE DEVELOPMENT
  - B) IMPREGNATION / FORMATION PROCESSES

* NEGATIVE ELECTRODE STUDY
  - A) MATERIAL UTILIZATION
  - B) LIFE LIMITING MECHANISM

* CELL / MODULE DEVELOPMENT EFFORT
  - A) BASIC CONFIGURATION
  - B) HARDWARE OPTIMIZATION
  - C) TRADE-OFF STUDY

* TESTING
  - A) ELECTRODE TESTING
  - B) CELL TESTS
  - C) COMPONENT TESTS

SUMMARY

VEHICLE TESTING
EAGLE-PICHER INDUSTRIES, INC.
JOPLIN, MISSOURI

I - VEHICLE - CONVERTED F-100 PICKUP
MANUFACTURED BY ELECTRIC VEHICLE ASSOCIATES
CLEVELAND, OHIO

II - VEHICLE - CONVERTED VW RABBIT PICKUP
MANUFACTURED BY SOUTH COAST TECHNOLOGY
DEARBORN, MICHIGAN

III - VEHICLE - VW TRANSPORTER VAN
MANUFACTURED BY VOLKSWAGEN OF W. GERMANY

		LEAD-ACID MILES	NICKEL-IRON MILES
I	"C" CYCLE	18.7 (VARTA)	62.5
	URBAN CYCLE	23.4	71.5
II	"C" CYCLE	22.1 (OLDHAM)	74.8
	URBAN CYCLE	35.3	91.0
III	"C" CYCLE	NOT TESTED	71.0
	URBAN CYCLE	36 (EV-106) ESB	103.0

APPENDIX

Solidarity House
8000 EAST JEFFERSON AVE
DETROIT MICHIGAN 48214
PHONE (313) 926-5000

INTERNATIONAL UNION, UNITED AUTOMOBILE, AEROSPACE & AGRICULTURAL IMPLEMENT WORKERS OF AMERICA—UAW

OWEN F. BIEBER, *PRESIDENT*

RAYMOND E. MAJERUS, *SECRETARY-TREASURER*

BILL CASSTEVENS • DONALD F EPHLIN • ODESSA KOMER • MARC STEPP • ROBERT WHITE • STEPHEN P YOKICH

VICE PRESIDENTS

February 21, 1985

Congressman Dan Glickman, Chairman
Subcommittee on Transportation, Aviation and Materials
House Committee on Science and Technology
2321 Rayburn House Office Building
Washington, D.C. 20515

Dear Mr. Chairman:

The UAW is submitting this letter for the record of our Subcommittee's hearings on the U.S. Department of Energy's transportation program and its FY 1986 funding. We appreciate your invitation to do so again this year.

As we testified before your Subcommittee in July 1981, and as we wrote you in February 1982, 1983 and 1984, we strongly believe that there needs to be much more, not less, government-sponsored automotive R&D. The decline in petroleum product prices since 1981, we fear, is creating within the industry a sense of false security with regard to the kind of vehicles that will be in demand in the years and decades ahead.

Much has been written about the supposed role of outsourcing -- both vehicles and engines/transaxles -- in reducing the domestic OEMs' costs and hence improving their competitiveness. The reality, however, is that through outsourcing and a deemphasis on new engine R&D, the U.S. is losing not only jobs but technological experience. With the U.S.-based producers showing growing signs of abandoning interest in domestic production of state-of-the-art small vehicles and their components, a government decision to abandon support for new, fuel-efficient engine R&D could well mean that when the next fuel shock hits, this country will no longer be competent to supply the products demanded by consumers in our home market.

Regardless of the decisions made in U.S. auto company board rooms, we insist, as we did last year, that the nation has a large stake in seeing that the commericalization of U.S.-generated automotive technology occurs in this country. Sadly, the Administration's proposed DOE transportation budget proposals illustrate once again its continuing failure to grasp this. Believing that only a passive, penny-wise and pound-foolish government is consistent with the "free market," it proposes to slash U.S. Stirling and gas turbine work, and to ignore the serious need to develop ceramic applications in diesel power plants.

This could be a disaster. In the case of Stirling work, it would pull the plug on research that reportedly is close to proving out an efficient, multiple fuel-compatible, clean, quiet power plant that could replace many of the imported engines used in and planned for domestically-assembled cars and light trucks. In particular, the MOD II -- if brought

to commercialization in the 1985-88 time frame -- can leapfrog Japan in heat engines, despite their far better-funded Stirling program. The MOD II program is still approximately three to five years ahead of the Japanese program, an advantage which would be sacrificed with reduced funding. Cutting U.S. Stirling, gas turbine, and adiabatic diesel contract work would send MITI the message that the U.S. has decided to cede the next generation of heat engines to Japan.

If the U.S. wants a competitive auto industry, we must decide to have one. A key element in that decision is government-funded power plant R&D. Despite meager past federal support, there are signs that spending is about to bear fruit. At a time when every other significant industrial country is nurturing high-risk research investments in the new engine (and especially ceramics) field, it would be the height of ignorance and arrogance for the United States to risk our auto industry's future in blind homage to free market ideology.

Again, our thanks for providing the UAW this opportunity for comment on the FY 1986 transportation program.

Sincerely,

Candace Howes
Research Economist

Dick Warden
Legislative Director

CH:pmb
opeiu494
DD3

W. B. Offutt
Vice President
Technical Management

Eaton Corporation
Engineering & Research Center
26201 Northwestern Highway
P. O. Box 766
Southfield, Michigan 48037

March 21, 1985

Honorable Dan Glickman
2324 Rayburn Building
Washington, D.C. 20515

Dear Mr. Glickman:

Currently pending before your Subcommittee on Transportation, Aviation and Materials is the President's FY 86 Budget Report for the Department of Energy's (DOE) Conservation Program. In the transportation section of the budget request, the President is asking for funding of the Electric and Hybrid Vehicle (EHV) Program at $6.1 million. Congress approved $8.4 million last year and $11.6 million the year before.

Eaton Corporation urges you and your Subcommittee to maintain this program at the 1985 level of $8.4 million in order to provide needed program continuity in this very important high-risk, alternative-energy research.

To date, DOE has been conducting significant research in the area of electric vehicles, particularly as it relates to improving powertrain efficiency and battery life and range. The technical momentum which has been created must be maintained. Today, the price of fuel is low and availability is good, but the world reserves of petroleum obviously are not limitless. Transportation using these fuels is vital to the U.S. Therefore, our national strategy must include developing transportation means which utilize alternate energy sources. The programs sponsored by DOE advance the state of the art and contribute measurably to our ability to compete in international markets and to provide defense against loss of transportation when conventional fuels are not available.

Over the past few years, and with the support and encouragement of government-sponsored programs such as EHV, Eaton engaged in long-term, highly sophisticated research and development of new transportation technologies. This kind of joint effort between industry and the federal government is fundamental if our country is going to respond forcefully to the government/industry partnerships being practiced by our international competitors.

Eaton, as well as others in the U.S. transportation industry, is willing to take the risks affiliated with basic, long-term R&D in order to develop cutting edge technologies. The technological breakthroughs which will flow from this research will greatly enhance the U.S.' ability to produce low-cost, energy-efficient transportation, and help reduce our nation's dependence on foreign energy sources.

Eaton is a major multinational corporation which has had a long involvement in the transportation sector of our economy. As a prime supplier of transportation technology for both the truck and automobile industries, we know from experience just how fiercely competitive and rapidly changing the international transportation market is.

EATON

We are ready and able to match our international competitors' efforts in these areas. However, where they enjoy a competitive differential based upon government support, U.S. industry by itself cannot compete in the world market. Electric vehicle and heavy-duty transport research and development, which is integral to our country's competitive posture in the transportation industry, needs your help.

Eaton firmly believes that, as a nation, we cannot afford to let our commitment to important long-term R&D programs such as these wane. Therefore, we believe that this Electric and Hybrid Vehicle program should be funded at least at the same level as last year, $8.4 million.

Should you or your staff desire more detailed information about Eaton's participation in these programs, I would be happy to provide it.

Sincerely,

W. B. Offutt jr

W. B. Offutt

WBO/vja

cc: Anthony C. Taylor, Staff Director, Subcommittee on Transportation, Aviation and Materials
J. Hushen, V.P.-Government Affairs
W. S. Coleman, General Manager, Corporate R&D - Detroit Center
L. Eltinge, Director of Research
T. Wissing, Manager, Government Contract Development & Administration

GTE Service Corporation

February 26, 1985

The Honorable Dan Glickman
Chairman, Subcommittee on Transportation,
Aviation and Materials
U. S. House of Representatives
Suite 2321, Rayburn Office Building
Washington, D.C.

Dear Representative Glickman:

In response to a request from Mr. Anthony Taylor I am providing you comments regarding the Department of Energy, DOE, FY 1986 Congressional Budget Request for Electric and Hybrid Vehicle, EHV, R&D. Specifically, I refer to the line item for the Electric Vehicle site operators Task Force Test and Evaluation funding. My remarks are made as Chairman of the EV Users Task Force as well as GTE's Electric Vehicle Program.

The site operator User Task Force (UTF) is comprised of organizations which have been active in the DOE Electric and Hybrid Vehicle Program for the past several years. In 1982, the UTF, working in cooperation with DOE staff, established the Product Improvement Test and Evaluation Program. This program is a vital link in the technology development chain since it provides the proving ground for the products which eminate from the component and vehicle systems R&D. UTF not only evaluates and verifies product performance but also provides a real world laboratory for infrastructure development (i.e. parts supply and maintenance systems).

The UTF has been instrumental in finding and testing many components which have allowed the continued use of most of the original electric vehicles. We are now testing and aiding in the development of advanced technology components which will assist in bringing about a viable electric vehicle. The funding necessary to completing this work has been and continues to be jointly funded by DOE and the private sector. To abolish this funding when we have come so far and are so near to completion of our task seems unthinkable.

Speaking from the user's perspective, we at GTE have utilized Electric Vehicles for over four (4) years. Through this experience we have gained an insight into the problems of the Electric Vehicle as well as an appreciation for the unique contribution the Electric Vehicle could make. It is clean, non-poluting and silent. With the proper mission assignment, it can perform well. When one considers the polution problems facing many of our major cities, it is not hard to see a number of ways in which this unique form of transportation could aid in overcoming some of these problems.

It is, therefore, our concern that by zeroing out this vital work a wrong signal will be sent to all that this is not a worthwhile program and when the need arises for this vehicle it will not be available. We would appreciate your help in carrying on this vital work.

Respectfully,

C. L. Hayden
Director-Energy Management
GTE Service Corporation

CLH:bjs:3384H

ELECTRIC
VEHICLE
DEVELOPMENT
CORPORATION

Feb 21 1985

February 19, 1985

The Honorable Dan Glickman
Chairman, Subcommittee on Transportation
Aviation and Materials
U.S. House of Representatives
Committee on Science and Technology
Suite 2321, Rayburn House Office Building
Washington, D.C. 20515

Dear Representative Glickman:

In response to a request from Mr. Tony Taylor, I am providing you comments regarding the Department of Energy, DOE, FY 1986 Congressional Budget Request for Electric and Hybrid Vehicle, EHV, R&D. As I stated in my testimony before this committee last year, the Electric Vehicle Development Corporation, EVDC, is an electric utility industry sponsored organization which has established a new-term objective of electric vehicle (EV) introduction into commercial fleets in the late 1980's and a longer term objective of personal vechicle introduction in the early 1990's.

The attainment of these objectives is based on a national effort to develop and introduce EVs in which the Department of Energy, Electric Power Research Institute, EPRI, and the DOE site operators User Task Force, UTF, as well as EVDC each play a vital role (see attachment).

In 1984, our first year of operation, EVDC has worked closely with DOE, EPRI, and UTF to develop project plans consistent with the national stratey. This cooperative planning has resulted in the following projects to be funded jointly by the utility industry and the federal government.

- The Electric Field Test Van Design Program - DOE and EPRI have executed a Participation Agreement to develop and test a d.c. powered van under a 50/50 cost share arrangement.

- Field Evaluation of GM/Bedford Electric Van - UTF and EVDC have agreed to evaluate the technical reliability and user acceptablity of the electric van produced by Bedford Commercial Vehicles, a subsidiary of General Motors.

- Lithium/Iron Sulfide Battery Development - DOE, EPRI, Argonne National Laboratory and the Tennessee Valley Authority, are sharing costs in the development and fabrication of this advanced high temperature battery system.

My review of the DOE FY 1986 Congressicnal Budget request indicates that the FY 1986 Electric and Hybrid Vehicle R&D Request has been set at zero for each of the above projects. These project activities are the result of several years of collaboration which has resulted in a close working relationship between the utility industry and the federal government in EV development. I am asking that the concept of a national effort be preserved and that your committee re-establish these important EV projects in the 1986 DOE EHV Program.

EVDC is pleased to have the opportunity to provide input to the Congressional Budget hearing process and we would welcome any request for additional information.

Sincerely,

Gerald H. Mader
President

Encl.

GM/nb

ELECTRIC
VEHICLE
DEVELOPMENT
CORPORATION

THE NATIONAL EFFORT TO DEVELOP AND INTRODUCE ELECTRIC VEHICLES

NATIONAL STRATEGY

The Department of Energy (DOE), the Electric Power Research Institute (EPRI), local utility and telephone companies as well as vehicle manufacturers -- the key electric vehicle (EV) stakeholders -- have adopted a national strategy for EV introduction. Representatives from these organizations have worked with the Electric Vehicle Development Corporation (EVDC) to establish two commercialization objectives. The initial objective is the development of an electric van and support system for use within commercial fleets. This van will utilize near-term battery and drivetrain technology. Plans are to deploy a market-acceptable commercial electric van in the late 1980's. Introduction of EVs into the broader personal transportation market -- the second objective, is tied to the availability of advanced battery and drivetrain technology which can satisfy the more demanding performance requirements of that market segment. The time frame for the introduction of an advanced EV is expected to be the early 1990's.

STAKEHOLDER COOPERATION

The cooperation and coordinated participation of the key EV stakeholders is required if this national EV introduction strategy is to be successful. The partnership which has been established between the federal government and the electric and telephone utility industries is a vital element needed to nurture this technology during its early stages of development and introduction. The table below shows the steps in EV technology introduction and the role which each key participant plays in accomplishing these steps:

	DOE	EPRI	UTF	EVDC
COMPONENT R & D:				
- Development	X	X		
- Field Testing/Improvement	X	X	X	
VEHICLE SYSTEMS DEVELOPMENT				
- Component Integration	X	X		
- Field Testing/Improvement	X	X	X	
INFRASTRUCTURE DEVELOPMENT			X	X
MARKET DEVELOPMENT				X

DOE AND EPRI

DOE and EPRI have established complimentary R&D programs in both component R&D and Vehicle Systems Development for near-term and advanced EVs. DOE emphasizes advanced EV techology, whereas EPRI emphasizes the near-term. DOE and EPRI are parallel funding battery and drivetrain R&D as well as jointly funding an "Electric Field Test Van" development program.

USER TASK FORCE

The site operator User Task Force (UTF) is comprised of organizations which have been active in the DOE Electric and Hybrid Vehicle Program for the past several years. In 1982, the UTF, working in cooperation with DOE staff, established the Product Improvement Test and Evaluation Program. This program is a vital link in the technology development chain since it provides the proving ground for the products which eminate from the component and vehicle systems R&D. UTF not only evaluates and verifies product performance but also provides a real world laboratory for infrastructure development (i.e. parts supply and maintenance systems).

ELECTRIC VEHICLE DEVELOPMENT COMPANY

The Electric Vehicle Development Corporation (EVDC) is a electric utility industry sponsored organization formed to advance the development and marketing of electric vehicles. EVDC has worked cooperatively with DOE, EPRI and UTF to establish performance and design specifications for near-term electric fleet vans. EVDC's important contribution to this national effort is to identify the most appropriate markets for commercial fleet electric vans and to promote the deployment of a large number of these vehicles within utility and other commercial fleets. As reliable EVs emerge from the development stage, EVDC works to position these products into the marketplace through local utility sponsored marketing efforts. The market deployment of these EVs involves the establishment of maintenance and service programs based on the results of UTF evaluations.

DOE FUNDING

Since the enactment of Public Law 94-413, the electric and Hybrid Vehicle Research, Development, and Demonstration Act, the DOE has been a major force behind the development of electric vehicles and related components in the United States. Successful electric vehicle introduction requires continued government funding for critical battery and powertrain R,D,T&E. In addition, continued funding of the field evaluations through the User Task Force is also critical as their activities both validate R&D results and provide the operating experience base necessary for launching private sector commercialization initiatives.

JOHNSON CONTROLS

Congressman Dan Glickman
Chairman
Transportation, Aviation
and Materials Subcommittee
House Science and
Technology Committee
2321 RHOB
Washington, D.C. 20515

February 25, 1985

Dear Congressman Glickman:

Enclosed are comments that we request be placed in the record of the February 26, 1985, authorization hearings on the Department of Energy's FY 1986 Conservation budget.

The comments pertain to the need for funding of lead-acid and zinc-bromine battery systems for electric vehicle applications.

We urge you to give these views your sincere consideration. We would be pleased to provide any additional information.

Sincerely,

JOHNSON CONTROLS, INC.

Vincent M. Halsall
Vice President of Engineering
Battery Division

Enc.

EAGLE PICHER

COUPLES DEPARTMENT
JOPLIN, MISSOURI

PRESENT STATUS

SPECIFIC ENERGY	-	50 WH/Kg
PEAK SPECIFIC POWER	-	104 W/Kg
VOLUMETRIC ENERGY DENSITY	-	108 WH/LITER
ENERGY EFFICIENCY	-	65-70 %
CYCLE LIFE	-	1000 CYCLES PLUS
COST	-	< $ 100/KWH

Hearings on FY 1986 Department of Energy
Conservation Budget - February 27, 1985

Testimony Submitted to:

Congressman Dan Glickman
Chairman
Transportation, Aviation and Materials
Subcommittee
House Science and Technology Committee

By:

Vincent M. Halsall
Vice President of Engineering
Battery Division
Johnson Controls, Inc.

Submitted February 25, 1985

We believe there are some facts that must be understood by the members of this Subcommittee in consideration of authorizing FY 1986 funds for Department of Energy Conservation budget. Our comments specifically address funding needs of advanced lead-acid and zinc-bromine battery systems for electric vehicle applications.

As background, Johnson Controls through its Battery Division, is the largest U.S. manufacturer of automotive batteries. We have been a subcontractor to the Department of Energy (DOE) for battery development since 1976 and have also served as a subcontractor to several electric vehicle development programs.

WHY FEDERAL SUPPORT SHOULD GO TO OUR "BEST BETS" IN ELECTRIC VEHICLE BATTERY TECHNOLOGY - NOT JUST TO HIGH-RISK, UNPROVEN SYSTEMS.

-The U.S. goal should be to help develop electric vehicle technology so that it can be commercialized in the next five or ten years, not to spend another ten years looking for a so-called "perfect" battery system. The nation has already been disappointed by a series of technologies offering nothing but "promise." We know which systems can do the job, let's not let them flounder.

-Proponents of eliminating funding for battery systems promising near-term results assume that private industry will provide the capital needed to bring them to the point of commercialization. This is not true. Our development of advanced lead-acid and zinc-bromine batteries for electric vehicles will come to a virtual halt if funding by the DOE is discontinued. We are strong advocates of a future electric vehicle market and have made significant investments in battery development. But the near-term likelihood of a sizeable market is too remote for us - without Federal support - to expend the capital needed to complete development of these systems.

-The U.S. Government must support U.S. industry in efforts to establish a technology that will reduce our reliance on foreign energy sources. While the 1970s are behind us, uncertainties of oil supplies are not. Electric vehicles can make a significant difference in avoiding the potential paralysis of our transportation system. The battery is the critical component in making this a reality.

FUNDING IS NEEDED FOR THE SYSTEMS WHICH WILL MAKE ELECTRIC VEHICLES A REALITY -- LEAD-ACID

-Lead-acid is the only system currently powering existing electric vehicles and will be the system needed to furnish reliable power for commercial electric fleets. It is the foremost system for which significant progress - of more than a 60% improvement in energy density - has been demonstrated under DOE research programs. Its improving performance is a moving baseline against which unproven, high-risk "advanced" systems must be measured. It is the only system for which additional performance gains (of 30% to 40%) can be confidently predicted.

-Development of of the lead-acid battery is not complete. While testing of our advanced cells by DOE supported laboratories has shown positive results, a significant amount of investment is required to meet established energy density goals.

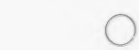
. . . AND ZINC-BROMINE

-The zinc-bromine battery is the only one of the so-called "advanced" systems considered for electric vehicles that is cost-effective both in terms of initial and life cycle costs, whose technical feasibility can be demonstrated, and which can claim significant progress in the past year.

-Federal funding is needed to continue this effort. Without it, the results of over 100,000 man hours of privately-funded research will be shelved.

IN SUMMARY

We believe that continued support by the DOE of electric vehicle battery systems is imperative to further the accomplishments of the past several years. To drop support of our best candidates for a viable electric vehicle battery would mean that the multi-million dollar investments of U.S. taxpayers and industry will have been a fruitless exercise.

Funding for long-term research is acceptable. But we need to fund the sure winners to ensure that electric vehicles play a meaningful role in ameliorating our petroleum dependency. Private industries, such as Johnson Controls, will not go it alone.

Thank you for giving these views your sincere consideration.